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Published in:
Sociedad Geologica de Espana. Revista

Publication date:
2010

Document Version
Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):
Vidal, M. D. P. C. (2010). Review of the Upper Jurassic-Lower Cretaceous stratigraphy in Western Cameros basin, Northern Spain. *Sociedad Geologica de Espana. Revista*, 23(2-3), 101-143.
http://www.sociedadgeologica.es/publicaciones_revista.html

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REVIEW OF THE UPPER JURASSIC-LOWER CRETACEOUS STRATIGRAPHY IN WESTERN CAMEROS BASIN, NORTHERN SPAIN

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Abstract: The Upper Jurassic-Lower Cretaceous stratigraphy of the Cameros basin has been reviewed. In Western Cameros the stratigraphic sections are condensed but they have a parallel development with the basin depocentre and the same groups have been identified. The Tera Group consists of two formations: Señora de Brezales and Magaña. The Oncala Group is represented by two formations of fluvial deposits, Jaramillo de la Fuente and Río del Salcedal and a third formation, Rupelo of lacustrine /coastal carbonates and evaporites. The Peñacoba Formation is an independent formation made of biogenic lacustrine carbonates and it is restricted to SW Cameros. The Urbión Group is represented by the Laguna Negra Formation which is the deposit of a gravelly braidplain and occurs in NW Cameros and South Demanda. The Enciso Group encompasses three formations, Río Ciruelos which is made of fluvial deposits, Hortigüela which consists of fresh water lacustrine carbonates and Golmayo representing a fluvial dominated coastal plain with marly lakes. The Oliván Group encompasses three formations of fluvial deposits: La Gallega, Castrillo de la Reina and Cuerda del Pozo. The Salas Group consists of two formations Cabezón de la Sierra and Abejar of fluvial and aeolian deposits.

The basin wide distribution of the Groups evidences the synchronous development of the rifting process across the basin and supports a model of a basin compartmentalised into multiple sectors evolving simultaneously under different rates of subsidence and terrigenous supply. The onlap of the syn-rift mega-sequence on the basin margins, the extra-basinal fluvial systems and shallow carbonate lakes together with its condensed character and the preservation of pre-rift mega-sequence at the basin margins point towards a basin with low-gradient basin margins.

Key-words: *Cameros basin, syn-rift mega-sequence, stratigraphy, Upper Jurassic-Lower Cretaceous, extensional tectonics, compartmentalization*

Resumen: Se revisa la estratigrafía del Jurásico Superior-Cretácico Inferior de la Cuenca de Cameros. En Cameros Occidental la estratigrafía está condensada pero tiene un desarrollo paralelo al del depocentro de la cuenca y los mismos grupos han sido identificados. El Grupo Tera está representado por dos formaciones: Señora de Brezales y Magaña. El Grupo Oncala incluye dos formaciones fluviales, Jaramillo de la Fuente, Río del Salcedal y una tercera formación, Rupelo de carbonatos lacustres. La Formación Peñacoba está formada por carbonatos lacustres biogénicos y tiene una distribución restringida en SW Cameros. El Grupo Urbión incluye la Formación Laguna Negra, constituida por conglomerados cuarcíticos y con una distribución en la mitad norte de Cameros Occidental. El Grupo Enciso incluye tres formaciones Río Ciruelos, de origen fluvial, Hortigüela de carbonatos oncolíticos lacustres y Golmayo de origen fluvial y costero lacustre. El Grupo Oliván está representado por tres formaciones fluviales: La Gallega, Castrillo de la Reina y Cuerda del Pozo. El Grupo Salas incluye dos formaciones: Cabezón de la Sierra y Abejar, ambas están constituidas por conglomerados cuarcíticos y areniscas conglomeráticas fluviales y eólicas y facies heterolíticas con carbón y una posible influencia mareal. La revisión estratigráfica evidencia la continuidad y relación genética de las asociaciones de facies fluviales y lacustres a escala de la cuenca, así como el desarrollo sincrónico del rifting en el depocentro principal, depocentros secundarios y márgenes flexurales poco subsidentes de la cuenca.

El rifting fue polifásico e incluyó ocho fases evolutivas que también están presentes en la mayor parte de las cuencas de Iberia. La distribución los grupos en todos los sectores de la Cuenca de Cameros sugiere a escala de cuenca, que el proceso de rifting fue sincrónico y apoya la hipótesis de un modelo de cuenca compartimentada en múltiple sectores con diferentes tasas de subsidencia y de aporte de



terrigenous. La relativamente buena correlación regional de los principales eventos tectónicos y sedimentarios sugiere que a la escala de una provincia extensional pequeña como Iberia durante el Jurásico Superior y el Cretácico Inferior, el proceso de rifting también fue sincrónico. El tipo de ambientes sedimentarios, sistemas fluviales extra-cuencas y lacustres carbonatados y evaporíticos someros, el carácter condensado y el solapamiento en los márgenes junto con la preservación de la mega-secuencia pre-rift dentro de la cuenca y en los márgenes sugiere una cuenca con márgenes de bajo gradiente.

Palabras clave: Cuenca de Cameros, megasecuencia syn-rift, estratigrafía, Jurásico Superior-Cretácico Inferior, tectónica extensional, segmentación.

Clemente, P. (2011): Review of the Upper Jurassic-Lower Cretaceous Stratigraphy in Western Cameros basin, Northern Spain. *Revista de la Sociedad Geológica de España*, 23 (3-4): 101-143.

The stratigraphy of extensional basins is a challenging task because frequently they are characterised by high rates of subsidence and terrigenous supply, compartmentalised into multiple sectors showing strong differences in thickness and lithofacies. Moreover, very often they have been subjected to post-rift tectonic inversion, folded, thrust, uplifted and partially eroded. These characteristics result into extraordinarily thick and complex mega-sequences, with recurrent facies and displaying frequent lateral / vertical changes in thickness and lithology. After the tectonic inversion, the syn-rift mega-sequences are cropping out partially eroded in basin sectors bounded by thrusts or inverse faults.

Two important questions in extensional tectonics are to know if across the basin, rifting is a synchronous or a diachronous process and the morphological relief of the basin margins (Jackson and MacKenzie, 1983; Morley, 1989; Walsh and Watterson, 1991; Friedman and Burbank, 1995). Both questions could be answered with the stratigraphy.

Syn or diachronous rifting implies two end types of basin models, the first one is a model where multiple sub-basins evolve independently (diachronously) and the second is a basin with multiple sectors evolving synchronously under different rates of subsidence (Jackson and MacKenzie, 1983; Morley, 1989; Walsh and Watterson 1991) and terrigenous supply.

A positive correlation of the stratigraphic units across all the sectors of the basin would evidence that rifting was a continuous process and it will support the compartmentalised basin model. To the contrary, the lack of correlations will show that rifting was a diachronous process and it will support the sub-basin model.

Basins with morphological relief and rift shoulders are characterised with the basin depocentre attached to the basin margin and conversely, the basin depocentre is detached from the margin in basins with low gradient margins (Friedman and Burbank, 1995). The degree of stratigraphic development and characteristics of the syn-rift mega-sequence at the basin margins could help to discriminate between these two types of basin margins.

In the basin depocentre, located in Eastern Cameros the syn-rift mega-sequence is extraordinary thick (up to

8000 m of cumulative thickness) and made of a large-scale alternation of open lacustrine carbonates and evaporites with distal fluvial deposits. In the Western Cameros terrigenous supplied margin the syn-rift mega-sequence is much thinner (2500-3000 m). The lower part is a monotonous succession of distal fluvial deposits punctuated by thin multi-storied units of channel sandstones. The upper part is a succession of proximal –middle fluvial deposits interrupted by several units of quartzitic conglomerates. Further west in the secondary depocentre of NW Cameros it is 1000-1300 m thick and consist of distal fluvial deposits interbedded with lacustrine carbonates and minor evaporites. In the adjacent terrigenous starved flexural margins of NW and SW Cameros the thickness is further reduced, the lower part is dominated by thick-bedded lacustrine palustrine carbonates and the upper part by thin units of distal fluvial deposits with calcic palaeosols.

The stratigraphy of this complex mega-sequence is due to a large number of authors. The first detailed stratigraphy of the Cameros basin was a combined study published in 1966 by Beuther (Western Cameros), Tischer (Eastern Cameros) and Kneuper-Haack (biostratigraphy) who described five groups, Tera, Oncala, Urbión, Enciso and Oliván consisting of informal units which were genetically related by lateral facies changes. So, these lithostratigraphic units were at the same time genetic units consisting of genetically related facies associations.

Later on, new stratigraphic units have been described by a large number of authors, in addition to the authors of the 1:50.000 geological maps by the Spanish Geological Survey (IGME), by Meléndez and Vilas (1982), Salomon (1982a,b), Guiraud and Seguret (1985), Platt (1989a,b,c), Clemente (1987, 1988), Clemente and Alonso (1988, 1990), Clemente (1991), Clemente *et al.* (1991), Clemente and Pérez-Arlucéa (1993), Alonso and Mas (1993), Mas, Alonso and Guimerá (1993), Gómez-Fernández and Meléndez (1994a) and by Mas *et al.* (2002, 2004) but never by revising the five groups initially described by Beuther (1966) and Tischer (1966). Additional biostratigraphic data has been provided by Brenner (1976), Schudack (1987), Schudack and Schudack (1989), Martín-Closas (1989), Martín-Closas y Alonso (1998), Hernández Samaniego *et al.* (1990), Muñoz *et al.* (1997) and Schudack and Schudack (2009).

Overall, the detailed stratigraphic work has been restricted to the lower half of the syn-rift mega-sequence, to the Tera and Oncala Groups and the stratigraphy of the Urbión, Enciso and Oliván Groups is largely unknown. Basically Beuther (1966) considered that the stratigraphy of Western Cameros was partially developed and that only the lower groups, Tera, Oncala and Urbión were present. Conversely Salomon (1982a,b) interpreted that the lower part was absent and the bulk of the fluvial deposits were included in the younger and newly defined Salas Group.

A detailed analysis of the stratigraphic and biostratigraphic data by previous authors suggests that the Enciso and Oliván Groups could be also present and that the Salas Group probably has different lithology and distribution than initially reported by Salomon (1982a,b). Moreover, the kind and rank of stratigraphic units are very heterogeneous and range from formal groups divided into informal units (Beuther, 1966; Tischer 1966), formations aggregated into genetic units: megacycles and cycles (Salomon, 1982b) into cyclothems (Guiraud and Seguret 1985), formations aggregated in groups (Platt 1989a,b,c) informal units forming part of unconformity bounded units (Gómez Fernández and Meléndez 1994) formal stratigraphic units forming part depositional sequences (Clemente *et al.*, 1991; Mas *et al.*, 1993). With some exceptions (Beuther 1966, Tischer 1966, Guiraud and Seguret 1985, Gomez-Fernández and Meléndez, 1994) the stratigraphic units are not homogeneous and there is not a clear hierarchy of the different units which can lead to a comprehensive understanding of the basin evolution and of the main tectonic and sedimentary events.

Instead of reviewing or redefining the stratigraphy by previous authors, most of the authors, choose to describe new stratigraphic units. Frequently the boundaries and the stratigraphic position of the stratigraphic units have been shifted up and down without new data or justification. In this way the successive lithostratigraphic units became quickly out of use. To a certain extend the definition of new units is understandable and related with the fact that, with few exceptions (Salomon, 1982b; Clemente and Alonso, 1990 or Gomez-Fernández and Meléndez, 1994), the formal stratigraphy never has been properly described and published. The stratigraphic units have been introduced in thematic publications and the descriptions are ambiguous so it is difficult to identify them in the field.

In general, the stratigraphic proceeding has been first to correlate the lacustrine carbonates and evaporites with biostratigraphic data (Tischer, 1966; Beuther 1966; Salomon, 1982a,b; Mas *et al.*, 1993) and later on to correlate the rest of the lithostratigraphic units by lithology, stratigraphic position (Salomon, 1982 a,b); sandstones petrofacies and provenance (Arribas *et al.*, 2003, 2007; González Acebrón *et al.*, 2007), and genetic stratigraphy (Beuther, 1966; Mas *et al.*, 1993; Gómez Fernández and Meléndez, 1994).

The most frequent correlation method has been the correlation of facies associations (fluvial-fluvial or most commonly fluvial –lacustrine carbonates and evaporites) thought to be genetically related under the framework of genetic stratigraphic sequences. Most of

the authors including Beuther (1966), Tischer (1966), Salomon (1982), and Guiraud and Seguret (1985), Clemente *et al.* (1991), Mas *et al.* (1993), Gomez-Fernández and Meléndez (1994) Casas *et al.* (2009) tried to correlate the fluvial deposits of the basin margin with the distal fluvial and lacustrine carbonates of the basin depocentre under the assumption that the syn-rift mega-sequence is characterized by genetic units with a mixed character and a bipartite stratigraphy, usually a lower unit of fluvial deposits in Western Cameros grades laterally to a unit of lacustrine carbonates or evaporites in the basin depocentre. Some of the fluvial deposits however represent large extra-basinal fluvial systems and imply a large volume of diluted waters which is in contradiction with the evaporitic character of the lakes. Correlations of lacustrine evaporites have been made under the assumption that evaporitic lake systems have a restricted distribution with respect to carbonate or siliciclastic systems, which appears not to be always the case (Anadón *et al.*, 1989; Bohacs *et al.* 2003).

The extraordinary thickness of the syn-rift mega-sequence, the proliferation and duplication of stratigraphic units, shifting of the stratigraphic position of the stratigraphic units, have resulted in a rather confusing picture. The main conclusion after these heterogeneous kinds, ranks and boundaries of the stratigraphic units is that the basin evolution was extremely complex and changeable in time and basically that rifting was a diachronous process where every sector of the basin treated as sub-basins evolved independently (diachronously).

Aims

The aims of this paper are to review the well-established stratigraphy of Beuther (1966) and Tischer (1966), to simplify the stratigraphy of Salomon (1982a,b), Platt (1989a), Clemente *et al.* (1991) Clemente and Pérez-Arlucéa (1993) and therefore of Martín-Closas and Alonso (1998) to constrain the correlations between the basin depocentre and the marginal sectors around the basin depocentre and the terrigenous supplied margin.

Minor changes needs to be made to the stratigraphy by Tischer (1966) of the Eastern Cameros basin depocentre whereas the stratigraphy by Beuther (1966) from Western Cameros needs to be fully revised.

The ultimate aims are to characterise the basin margin and to discriminate between two basin models between a model of sub-basins evolving independently (diachronously) or a model of a basin compartmentalised into multiple sectors evolving synchronously but under different rates of subsidence and terrigenous supply.

The Cameros basin has common characteristics with other Upper Jurassic-Lower Cretaceous basins of Iberia such as the Basque-Cantabrian, Organya, Maestrazgo, South Iberian Through, Asturias and Lusitanian basins. The stratigraphy of fluvial dominated basins and terrigenous supplied margins is also a common problem in the Devonian basins of Ireland and Greenland and in the Permo-Triassic basins of Iberia and North Sea or in the Newark basin.

Methodology

The followed stratigraphic procedure has been first to do a minor review of the stratigraphy by Tischer (1966) in the basin depocentre and later on a detailed revision of the stratigraphy by Beuther (1966) in Western Cameros. Groups are lithostratigraphic units defined by its constituting formations (Salvador *et al.*, 1994) but the groups of Beuther (1966) and Tischer (1966) consist of informal units. Therefore the lower rank formal or informal stratigraphic units- formations and members- of later authors (of Salomon, 1982a; Platt 1989a; Clemente and Alonso, 1990; Clemente *et al.*, 1991; Clemente and Pérez-Arlucéa, 1993) have been reviewed and described as aggregated formations within the Groups of Beuther (1966) and Tischer (1966) which are well-established in the literature.

The revisions have been made following the priority criteria, the degree of establishment or its usefulness to understand the basin (Salvador *et al.*, 1994). By doing so, by the aggregation of lithologically associated formations within the Groups of Beuther (1966) and Tischer (1966) the 'genetic' correlations between Western and Eastern Cameros are readily established. Similar rocks which include important unconformities should not be described as a single unit (Salvador *et al.*, 1994) and therefore new formations have been defined to describe the fluvial deposits, the successive units of quartzitic conglomerates of the upper part of the syn-rift mega-sequence.

The stratigraphic review is based on field work, detailed mapping and cross correlation of 49 stratigraphic measured sections, integrating fluvial and lacustrine sedimentology, petrology and provenance of conglomerates and sandstones, and biostratigraphy of pollen and spores from the fluvial deposits and ostracods and charophytes from the lacustrine carbonates.

Stratigraphic sections were described on a 1:250 scale, involving in total the measurement and description of more than 12000 metres of sedimentary rocks. In addition another 15 key sections have been studied but not measured. These are Río Arlanza; Villoslada de Cameros, South limb of Río Duero anticline, Canredondo, Pico San Martín, Almajano (Majadas del Palmero), Calderuela, El Pegado, Castillejo de San Pedro, San Pedro Manrique, Río Cidacos, San Román de Cameros, Robres del Castillo, Leza and Arnedillo.

In the measured sections, bed thickness, lithology, sedimentary structures, fossil content and palaeocurrents were recorded. Sampling was directed first to the biostratigraphy of pollen and spores in floodplain mudstones and siltstones and by charophytes and ostracods in the marls. Additional sampling was directed to carbonate facies analysis and petrology- provenance of sandstones and conglomerates.

The available biostratigraphic data is from palynomorphs, charophytes and ostracods. The palynomorphs are from the Enciso Group (Golmayo, Río Ciruelos Formations), Oliván Group (Castrillo de la Reina Formation) and Salas Group (Abejar Formation). The charophytes and ostracods are from the Oncala

Group (Rupelo Formation), Peñacoba Formation, Enciso Group (Hortigüela, and Golmayo Formations).

The large thickness of the syn-rift mega-sequence and numerous facies changes imply a large number of lithostratigraphic units, therefore the present contribution focuses on general characteristics of the Groups and aggregated formations. It encompasses a thorough description of the Peñacoba and Laguna Negra Formations. The detailed stratigraphy of the Oncala, Enciso, Oliván and Salas Groups or the correlation with sub-surface data will be presented in separate papers.

Geological setting

The Upper Jurassic-Lower Cretaceous rifting stage took place in the Western Astur Leonese and the Cantabrian Zones that are located in the intermediate and external parts of the former Variscan orogen within a vast landscape of carbonate rocks originated by the sub-aerial exposure of the Jurassic carbonate platforms. The rifting episode was associated with the northwards expansion of the North Atlantic, the divergent movement of Europe and Iberia, the opening of the Biscay Bay and with the southern expansion of the Tethys rift (Ziegler, 1989; García Mondejar, 1989; Salas and Casas, 1993).

The extensional province was compartmentalised by NW-SE extensional faults and by NE-SW transverse faults and included several depocentres (Asturias, Basque-Cantabrian, Organya, Cameros, South Iberian Trough, Maestrazgo) separated by highs without sedimentation. A distinctive characteristic of the rifting stage was the preservation of the pre-rift mega-sequence adjacent to the basin margins.

The rifting was poly-phasic and lasted 40-45 m.y. It was characterised by extremely high rates of subsidence, evidenced by enormous successions of marine and of lacustrine carbonates and in the basins close to the Iberian Massif of terrigenous supply. Rifting was followed, during the Upper Cretaceous by a 30-35 m.y. long post-rift period of thermal subsidence and tectonic stability. The post-rift stage was characterised by the homogenisation of the Biscay Bay and Tethys realms and marked with the onlap of fluvial deposits of the Utrillas Formation on the pre-rift mega-sequence and on the Variscan basement (Fig.1; Floquet *et al.*, 1982; Salomon, 1982a,b; Gil and García 1996). The sub-tropical latitudinal position of Iberia and associated warm climate favoured the deposition of shallow marine carbonates (Floquet *et al.*, 1982; Alonso *et al.*, 1993).

In the Tertiary, the relative movement of Iberia, Europe and Africa changed from divergence to convergence which resulted in the tectonic inversion of the extensional basins and two collisional orogens, the Cantabrian-Pyrenees in the north and the Betic in the South (Fig. 1). The stress originated at these collisional orogens was transmitted to the plate interior and resulted in the uplift of several intra-plate mountain chains (Fig. 1; Julivert *et al.*, 1972; Álvaro *et al.*, 1979; Guimerá, 1983; Ribeiro, *et al.*, 1990; Vegas *et al.*, 1990; Vegas, 2005, 2006).

The Spanish Central System and the Portuguese Central Range originated in the Central Iberian Zone of

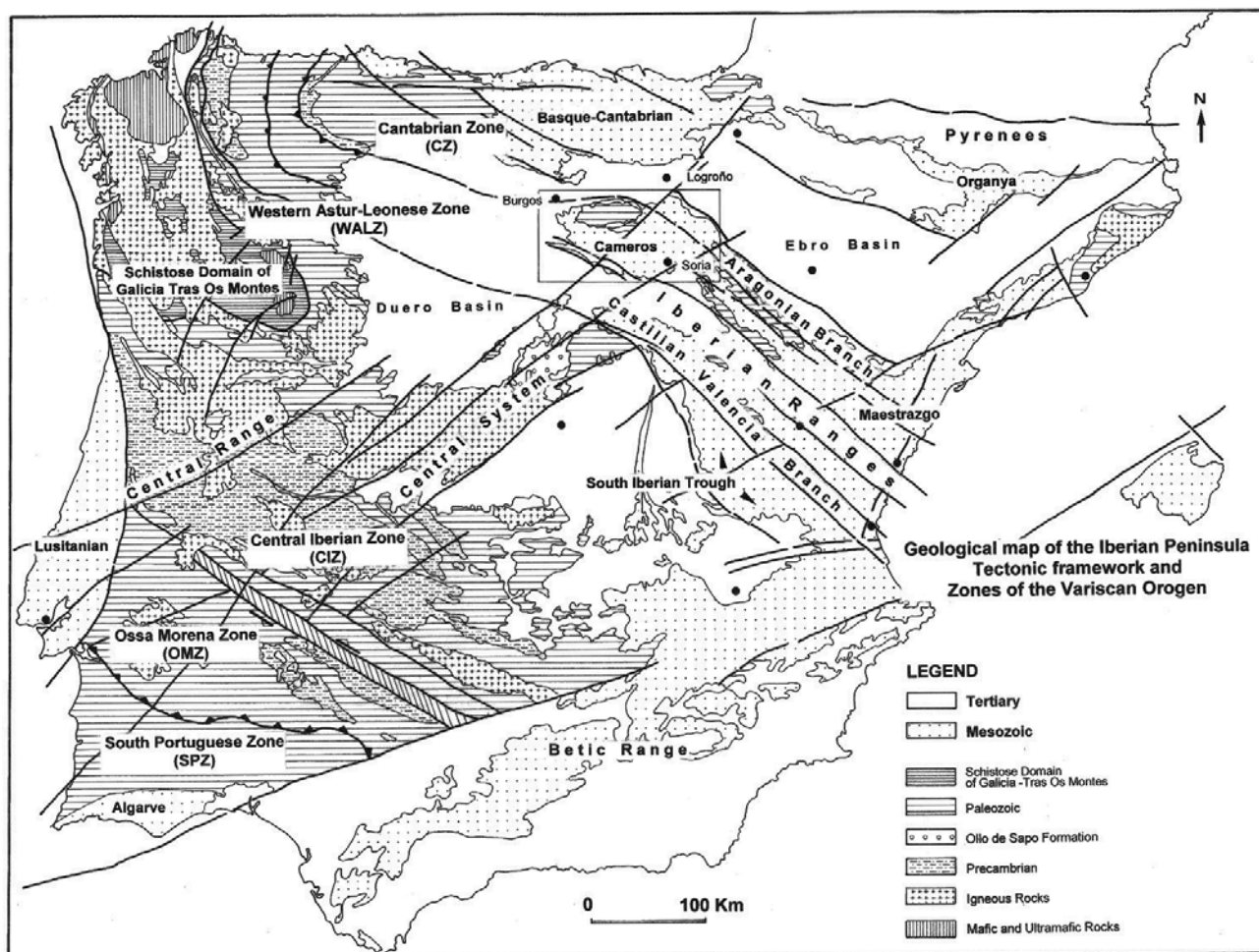


Figure 1.- Geological map of Iberia at the end of the Tertiary Alpine tectonic deformation, showing the uplift and partial erosion of the Mesozoic mega-sequence and the underlying Variscan basement. The map illustrates the geology of the Variscan orogen, the Mesozoic, mostly the Upper Cretaceous and the Tertiary basins. Super-posed is the location of the Upper Jurassic-Lower Cretaceous basins. The geology of the Iberian Massif is modified after Julivert *et al.* (1972), the tectonic framework is modified after Vegas (1974), Vegas and Banda (1982) and Salas *et al.* (1995). The geology of the Tertiary and Mesozoic is modified after Lanaja *et al.* (1987).

the Variscan basement- in the so-called basement without sedimentary cover (Fig. 1; Álvaro *et al.*, 1979; Vegas, 2005, 2006). The Iberian Ranges originated in the extended basement of NE Iberia, in the area involved by the Mesozoic extensional tectonics (Fig. 1, Álvaro *et al.*, 1979; Guimerá and Álvaro, 1993; Vegas, 2005, 2006). The Iberian Ranges have a general direction NW-SE and are broadly perpendicular to the Spanish Central System - Portuguese Central Range (Fig. 1). In the Iberian Ranges, tectonic inversion took place by the reactivation of the extensional faults as thrusts and inverse faults but also by newly formed thrusts and faults (Álvaro *et al.*, 1979; Guimerá and Álvaro 1990, Ribeiro *et al.*, 1990, Vegas *et al.*, 1990; Casas Sainz, 1993; Mata *et al.*, 2001; de Vicente *et al.*, 2004; Vegas, 2005, 2006).

The Iberian Ranges consist of four major allochthonous tectonic units Cameros, the Aragonian Branch, Maestrazgo and the Castilian-Valencia Branch (Fig. 1). These units are forming part of a bi-vergence fold and thrust belt, with SW dipping thrusts in North Cameros, the Aragonian Branch and Maestrazgo and NE dipping thrusts in South Cameros, and in the Castilian Valencia Branch (Fig. 1; Álvaro *et al.*, 1979; Guimerá, 1983; Casas Sainz, 1993; Casas Sainz and Gil-Imaz, 1998).

The Cameros allochthonous unit

The Cameros allochthonous unit is located at the NW end of the Aragonian Branch of the Iberian Ranges, overthrusting in the north and northeast the Rioja Trough, in the southwest and southeast, the Ebro basin and in the SE the Duero and Almazán basins (Figs. 1, 2 and 3). The northern and northeast border with the Rioja Trough and Ebro basin is delineated by the Cameros Thrust, the SW border with the Duero basin is characterized by blind thrusts and the SE border with the Almazán basin is delineated by NE-SW and NW dipping thrusts (Figs. 1, 2 and 3; Casas Sainz, 1993; Guimerá *et al.*, 1995; Casas and Maestro, 1996; Maestro-González *et al.*, 1997).

The Cameros Unit has asymmetric wedge geometry; it is extraordinarily thick and gently folded in the central part of eastern Cameros (Figs. 2 and 3). Thickness decreases towards Western Cameros Central sector but due to the existence of thick, competent units of quartzitic conglomerates it is also gently folded (Figs. 2, 3). It is much thinner and deeply folded and/or thrust at the NE Cameros, SW Cameros, NW Cameros margins (Figs. 1 and 2). The dominant direction of the Alpine

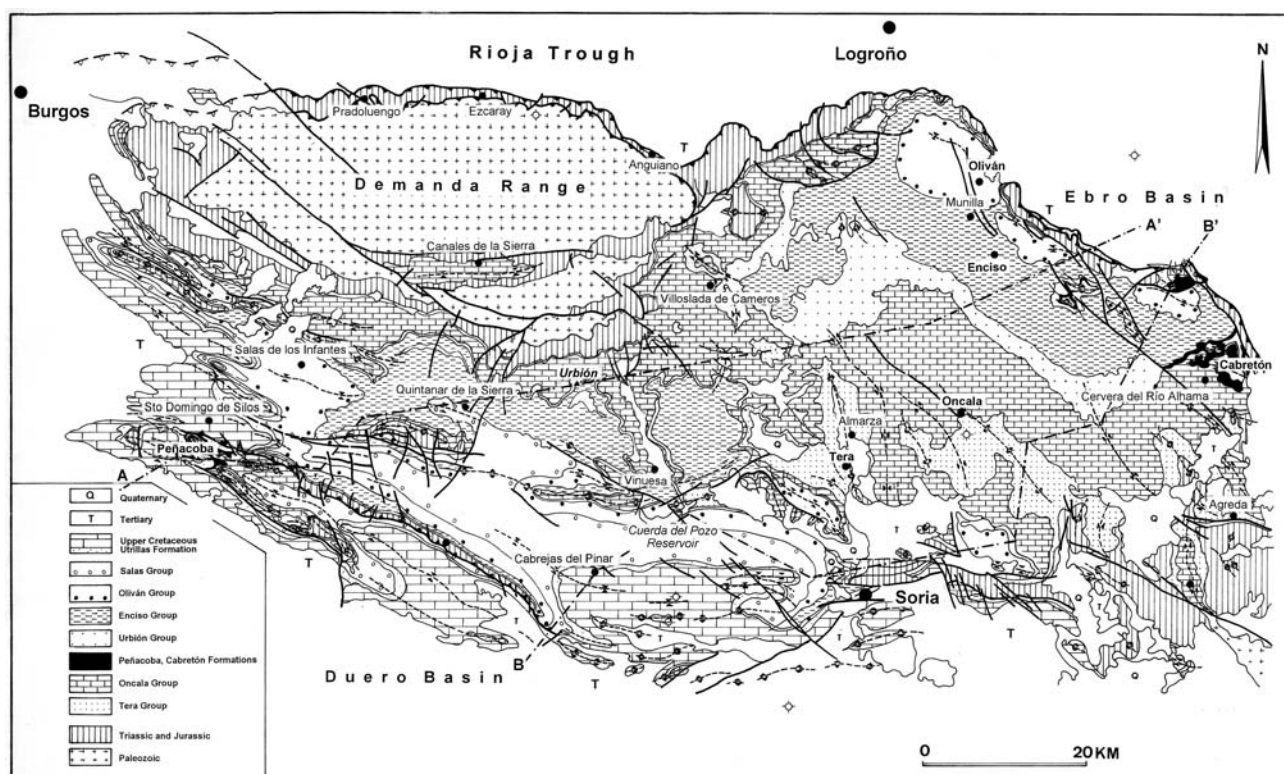


Figure 2.- Geological map of the Cameros Allochthonous Unit with the Alpine tectonic structures showing the basin wide distribution of the Tera, Oncala, Urbión, Enciso, Oliván and Salas groups and the restricted distribution of the Peñacoba and Cabretón Formations to SW and SE Cameros. In the Demanda Ranges part of the Palaeozoic and the complete Mesozoic sequence have been eroded. The map is a modified synthesis after the 1:50.000 geological maps by Esnaola Gómez *et al.* (1973); Boquera Fillol *et al.* (1978a, b); Gil Serrano *et al.* (1978); Beltrán Cabrera *et al.* (1980) Cámara and Durántez (1981, 1982), Rey de la Rosa and Rivera Navarro (1981a,b), Durántez *et al.* (1982) Hernández Samaniego *et al.* (1990), Ramírez Merino *et al.* (1990). It is also partly based on Salomon (1982a, b), Guiraud and Seguret (1985) Gómez-Fernández and Meléndez (1994a) and Espina *et al.* (2002).

structures is NW-SE; secondary structures have NE-SW and W-E strike (Figs. 2 and 3).

The most significant Alpine tectonic structures are in the north border, the Cameros Thrust and in the southern border, the San Leonardo and Sierra de la Pica thrusts (Figs. 2 and 3). The main folds are the Munilla-Arnedillo and Valdeprado synclines and the Oncala anticline (Figs. 2 and 3). The SE margin with the Aragonian Branch is delineated by a succession of anticlines, El Pegado, Inestrillas and Valdegutur (Figs. 2 and 3). Further south are the Calderuela, Canredondo and Picofrentes synclines and the Tera and Duero anticlines (Figs. 2 and 3). In addition to the thrusts and folds the overall area is deeply affected by many small, meter scale inverse faults.

The present day outcrops do not match the original basin, which was larger. The presence of the syn-rift mega-sequence in the Villavelayo syncline and further north, in the hanging wall of the Cameros thrust (Figs. 2 and 3; Schudack, 1987; geological maps) indicate that a continuous basin existed all over the area but that the corresponding deposits have been eroded during the Tertiary tectonic inversion and uplift of the Demanda Block (Figs. 1 and 2). Moreover, seismic profiles and oil wells located in the South of the Rioja Trough indicate the presence of Upper Jurassic- Lower Cretaceous deposits buried below the Tertiary of the La Rioja Trough (Lanaja *et al.*, 1987; Casas Sainz, 1993; Mas *et al.*, 1993; Guimerá *et al.*, 1995 and Mata *et al.*, 2001; Casas Sainz and Gil-Imaz, 1998).

The Upper Jurassic-Lower Cretaceous stratigraphy together with the Alpine tectonic structures evidence that the basin was compartmentalized into multiple sectors and included a main depocentre located in Eastern Cameros, a terrigenous supplied margin in Western Cameros and several secondary depocentres and flexural areas in Western and Eastern Cameros (Figs. 2 and 3; Beuther, 1966; Tischler, 1966; Salomon, 1982a,b). Western Cameros is further compartmentalized into four large sectors and sub-sectors 1) Western Cameros Central Sector (South Demanda, hanging wall block of the Moncalvillo Fault, hanging wall of the San Leonardo Thrust, 2) NW Cameros secondary depocentre and adjacent flexural area 3) SW Cameros flexural area and 4) Soria-South Cameros- (Southern limb of the Río Duero anticline, Canredondo, Calderuela synclines) (Figs. 2 and 3).

Stratigraphy of the Upper Jurassic – Lower Cretaceous syn-rift mega-sequence in the basin depocentre

General characteristics

At the basin depocentre the Upper Jurassic-Lower Cretaceous is up 8000 m of cumulative thickness and made up of fluvial siliciclastics and lacustrine/coastal carbonates and evaporites (Fig. 4). The lower part (600 m) is dominated by distal fluvial deposits followed by

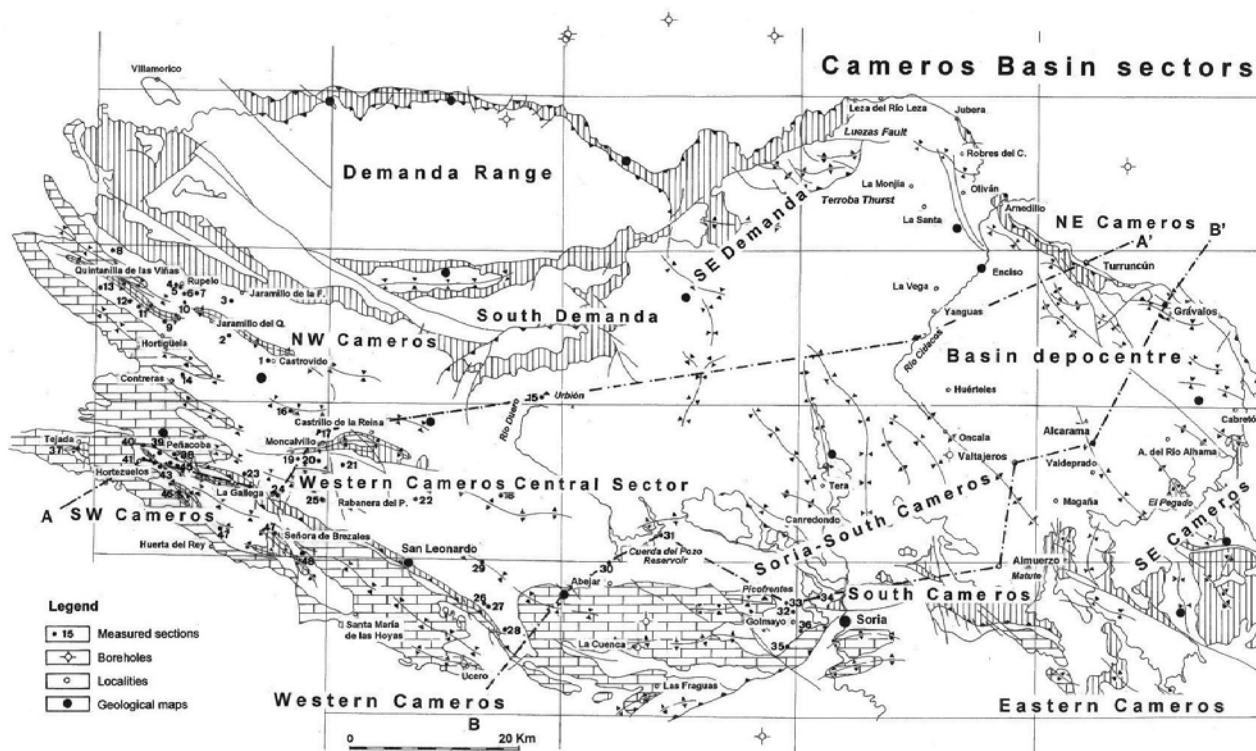


Figure 3.- The Cameros basin geological map showing the main Alpine tectonic structures, the basin sectors and the location of the measured stratigraphic sections. Superposed is the network of the 1: 50.000 geological maps. The sections are: 1. Castrovido, 2. Pinilla de los Moros, 3. Jaramillo de la Fuente, 4. Rupelo 1, 5. Rupelo 2-Río Cabrera, 6. Rupelo-Molino de Zoilo, 7. Río de San Marcos, 8. Torrelara, 9. Hortigüela, 10. Villaespa, 11. Mambrillas de Lara, 12. Arroyo Cabezuela, 13. Quintanilla de las Viñas, 14. Contreras, 15. Urbión, 16. Castrillo de la Reina, 17. Moncalvillo (Río Círuelos), 18. Cruz del Roblellano, 19. Cabezón de la Sierra, 20. Matarredonda, 21. Arroyo de la Vega, 22. Arroyo del Sotón, 23. Pinilla de los Barruecos, 24. La Gallega, 25. Rabanera del Pinar, 26. Talveila 1, 27. Talveila 2, 28. Cubilla 1, 29. Mojón Pardo, 30. Abejar, 31. Cuerda del Pozo, 32. Río Golmayo, 33. Soria-Picofrentes, 34. Garay, 35. Hoya del Moro, 36. Arroyo de Rades, 37. Tejada, 38. Peñacoba, 39. Hortezielos 1 -El Helechal, 40. La Yecla, 41. Hortezielos 2 -Las Huertas, 42. Hortezielos 3 -Cauce 1, 43. Hortezielos 4 -Cauce 2, 44. Manantial de la Mina, 45. Las Cabezas, 46. Doña Santos, 47. Huerta del Rey, 48. Señora de Brezales and 49. Collado de Valgrande.

up to 3000 m whitish ochre carbonates and evaporites displaying a relatively well developed cyclicity (Fig. 4; Salomon 1982 a,b).

This huge succession of thin-bedded limestones, paper shales, marls and evaporites is punctuated by thin units of thick-bedded limestones and breccias, as well as by thin units of black, bituminous carbonates and evaporites (Figs. 4; Tischer, 1966; Salomon, 1982 a,b; Gómez-Fernández and Meléndez, 1994a,b). It follows 2500-3000 m of fluvial deposits divided in the middle part by the extensive, 100-120 m thick newly defined La Vega Formation of reddish mudstones and siltstones (Fig. 4, Clemente unpublished data after the C₁₂3a1 unit of Cámara and Duránte, 1981). The lower half is further characterised by the presence of thin units of multi-storied channels of pebbly conglomerates of vein quartz and quartzites and thin laterally discontinuous units of lacustrine siliciclastics with diverse fauna (Fig. 4; Cámara and Duránte, 1981). Upwards La Vega Formation is overlaid by a thin unit of multi-storied channel sandstones and further upwards follows a monotonous succession of fluvial deposits that gradually change to the lacustrine siliciclastics and carbonates of the Enciso Group (Fig. 4).

These lacustrine carbonates are punctuated by a thin unit of dark coloured, bituminous marl, marly

mudstones with ostracods (Fig. 4). The upper part (1500-2000 m) of the syn-rift mega-sequence preserved after the Tertiary erosion is the Oliván Group which consists of two formations of distal fluvial deposits with differential development of flood plain and channel sandstones where the second is more frequent in the upper part (Fig. 4; Cámara and Duránte, 1981; Hernández Samaniego *et al.*, 1991). In addition, the group includes a thin intercalation of shallow marine carbonates (Mas *et al.*, 2002, 2004).

Moreover in SE Cameros unconformable overlying Oncala Group is the Cabretón Formation which includes the C₁₁3c, and C₁₁3 units of Duránte *et al.* (1982) and two units of Salinas and Mas (1989, 1990): the Lower Heterolithic Unit and the Cabretón Limestones Unit (s.s). The lacustrine carbonates are dark coloured to black limestones and marls with charophytes and ostracods (Tischer, 1966; Duránte *et al.*, 1982; Salinas and Mas, 1989, 1990).

Stratigraphy and sedimentary environments

An accurate stratigraphy of the Eastern Cameros basin depocentre is important in order to understand the correlations and the stratigraphy of the Western Cameros quartzitic conglomerates and quartz-

feldspathic sandstones as well as the lacustrine/palustrine carbonates. As it has been stated in the introduction, the stratigraphy by Tischer (1966) is still valid but small changes need to be made.

In the basin depocentre the syn-rift mega-sequence is organised into six lithostratigraphic Groups Tera, Oncala, Urbión, Enciso, Oliván and Salas and one independent formation, Cabretón (Figs. 2, 5). These groups are bounded by regional unconformities and consist of associated formations with significant unifying lithologic features (Salvador *et al.*, 1994) and therefore genetically related and time-equivalent deposits (Fig. 5; Beuther, 1966; Tischer, 1966).

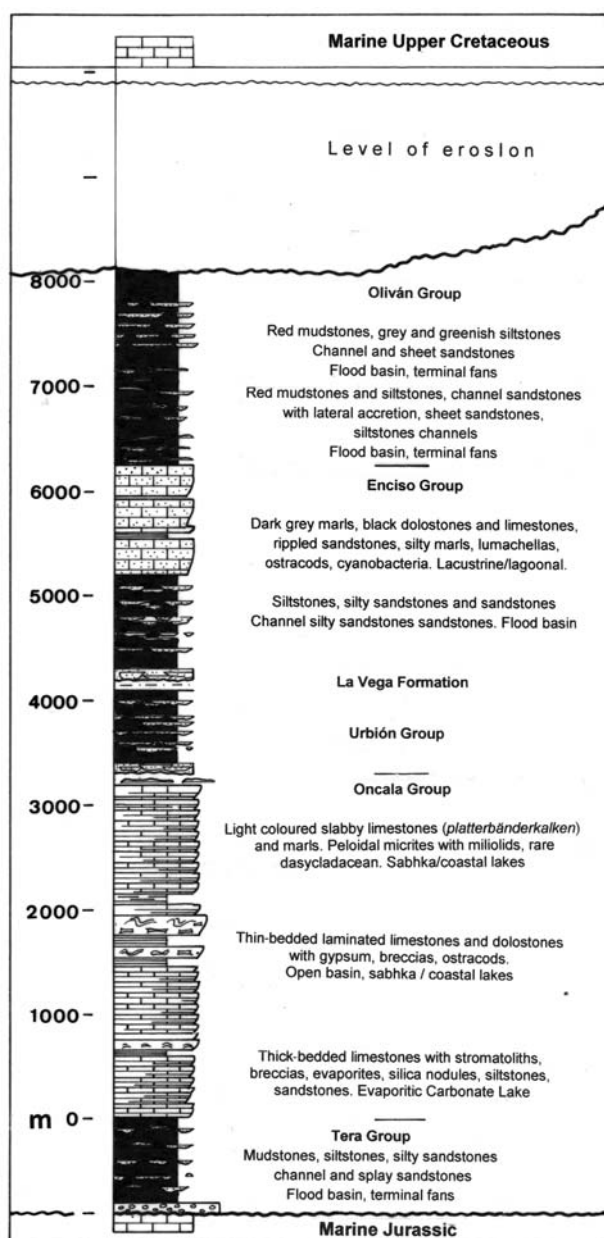


Figure 4.- General characteristics of the syn-rift mega-sequence in the basin depocentre. It is a composite section encompassing the Pegado anticline, the Valdeprado syncline and the southern limb of the Arnedillo –Munilla syncline sections. It is partly based on Rey de la Rosa and Rivera Navarro (1981b), Cámara and Durántez (1981), Salomon (1982a, b) and Gómez-Fernández and Meléndez (1994a, b).

The Tera Group- is 500-600 m thick and consists of alluvial and fluvial deposits included in the Jubera (Díaz Martínez, 1988; Hernández Samaniego *et al.*, 1990), Agreda (Gómez-Fernández and Meléndez 1994 a) and Magaña (Salomon, 1982a,b) Formations (Fig. 5). The Magaña Formation has a restricted distribution to eastern Cameros (Figs. 2 and 5; Salomon 1982 a,b). It represents the deposits of a large fluvial system with a SW-NE proximal distal trend (Gomez-Fernández and Meléndez, 1994a) and a terminal fan with ephemeral discharges. Biostratigraphic data of charophytes from the Jubera Formation indicate a Portlandian –Berriasian age (Hernández Samaniego *et al.*, 1990) and from the Agreda Formation indicate a Tithonian age (Martín Closas in Gomez-Fernández and Meléndez, 1994).

The Oncala Group is fully developed and up to 3000 m thick in the NE of the Oncala anticline where it is dominated by lacustrine/ coastal thin-bedded limestones, paper shales and evaporites (Figs. 4, 5 and 6). They are forming part of the Río Alhama (Salomon, 1982a,b), Huérteles and Valdeprado Formations (Guiraud and Seguret, 1985) (Figs. 5, 6).

In the SW limb of the Oncala anticline, (Calderuela and Canredondo synclines and Río Duero anticline, Figs. 2 and 7) the group is much thinner (600 m) and condensed, represented by the Matute Formation, which consists of four intervals of thick-bedded limestones separated by thin intercalations of fluvial mudstones, siltstones and minor sandstones (Figs. 5 and 7). In the lower –middle part silica nodules and layers after selenitic gypsum are a common feature. This formation wedges out in the southern limb of the Río Duero anticline where it is dominated by lacustrine-palustrine carbonates and palaeosols (Figs. 2 and 7).

In NE Cameros the Group is represented by the Río Leza Unit of Hernández Samaniego *et al.* (1990) and Leza Formation of Díaz Martínez (1988) and Alonso and Mas (1993). This formation is 70-100 m thick, the lower part consists of thick-bedded limestones and the upper part of thin-bedded orange dolostones and grey laminated limestones with evaporites. The formation is characterised with flora and fauna of marine affinity which includes dasycladaceans, benthonic foraminifera and echinoids (Alonso and Mas, 1993).

The biostratigraphic data from the Leza Formation is in principle contradictory and so it is its stratigraphic position. Biostratigraphic data from charophytes by Hernández Samaniego *et al.* (1990) point toward a Malm-Berriasian age and consequently it was included in the Purbeck and in the basal part of the syn-rift mega-sequence. Biostratigraphic data from dasycladaceans by Alonso and Mas (1993) point towards an Aptian age and consequently the formation has been included in the Enciso Group and in the upper part of the syn-rift mega-sequence.

His stratigraphic position, however between the Portlandian–Berriasian Jubera Formation and the Hauterivian–Barremian Hornillo de Cameros –Munilla Unit of Hernández Samaniego *et al.* (1990) together with the facies associations and sedimentary environments, clearly favours an attribution to the Oncala Group.

The sandstones of the Oncala Group are sub-arkoses with K-feldspars and plagioclases (Rey de la Rosa and Ribera Navarro, 1981a,b; González Acebrón *et al.*, 2007, 2010 a,b).

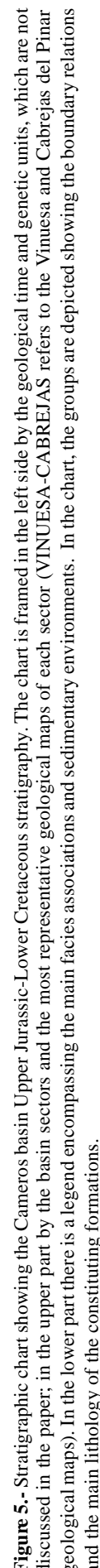


Figure 5.- Stratigraphic chart showing the Cameros basin Upper Jurassic-Lower Cretaceous stratigraphy. The chart is framed in the left side by the geological time and genetic units, which are not discussed in the paper; in the upper part by the basin sectors and the most representative geological maps of each sector (VINUESA-CABREJAS refers to the Vinuesa and Cabrejas del Pinar geological maps). In the lower part there is a legend encompassing the main facies associations and sedimentary environments. In the chart, the groups are depicted showing the boundary relations and the main lithology of the constituting formations.

The Oncala Group represents the deposits of a huge evaporitic carbonate lake-complex with the open basin in the NE limb of the Oncala anticline (Tischer 1966, Salomon 1982a,b, Gomez-Fernández and Meléndez 1994a,b) dominated by biochemical processes. The basin margins were typified by low-gradient carbonate ramps and represented by the Leza Formation in NE Cameros and by the Matute Formation in Soria-South Cameros sector (Fig. 5). The lower middle parts probably are the deposits of a hydrologically closed basin which evolved in the upper part towards a semi-enclosed basin open to the north, to the Biscay Bay.

Unconformable overlying the Oncala and Tera Groups and the marine Jurassic (Durántez *et al.*, 1982) the Cabretón Formation is 100-120 m and the lower part (40 m) consists of by flood plain mudstones, marly mudstones and marls intercalated with beds of detrital limestones. The upper part is 20-80 m thick and dominated by carbonates: two limestone lithosomes which towards the NE became amalgamated in only one (Salinas and Mas, 1990). Following these authors, the most characteristic facies association are erosive based sandy limestones banks consisting of grainstones and packstones of bivalves and ostracods with cross stratification. The Cabretón Formation is the deposit of a lacustrine basin with distributary channels (Salinas and Mas, 1989, 1990).



Figure 6.- Lower part of the Oncala Group in the Pegado anticline where the Río Alhama Formation is topped with a unit of bituminous carbonates and thick bedded stromatolitic limestones.

The biostratigraphic data and stratigraphic position of the Cabretón Formation is also under discussion. Biostratigraphic data by Martín-Closas (1989) and Martín-Closas and Alonso (1998) from the lower part-the Lower Heterolithic Unit of Salinas and Mas 1989, 1990)- point towards a Lower Berriasian-Valanginian age whereas biostratigraphic data from the upper part-from the Cabretón limestones (s.s)- point towards a Valanginian- Hauterivian age. Recent biostratigraphic data of ostracods from the Cabretón limestones (s.s)

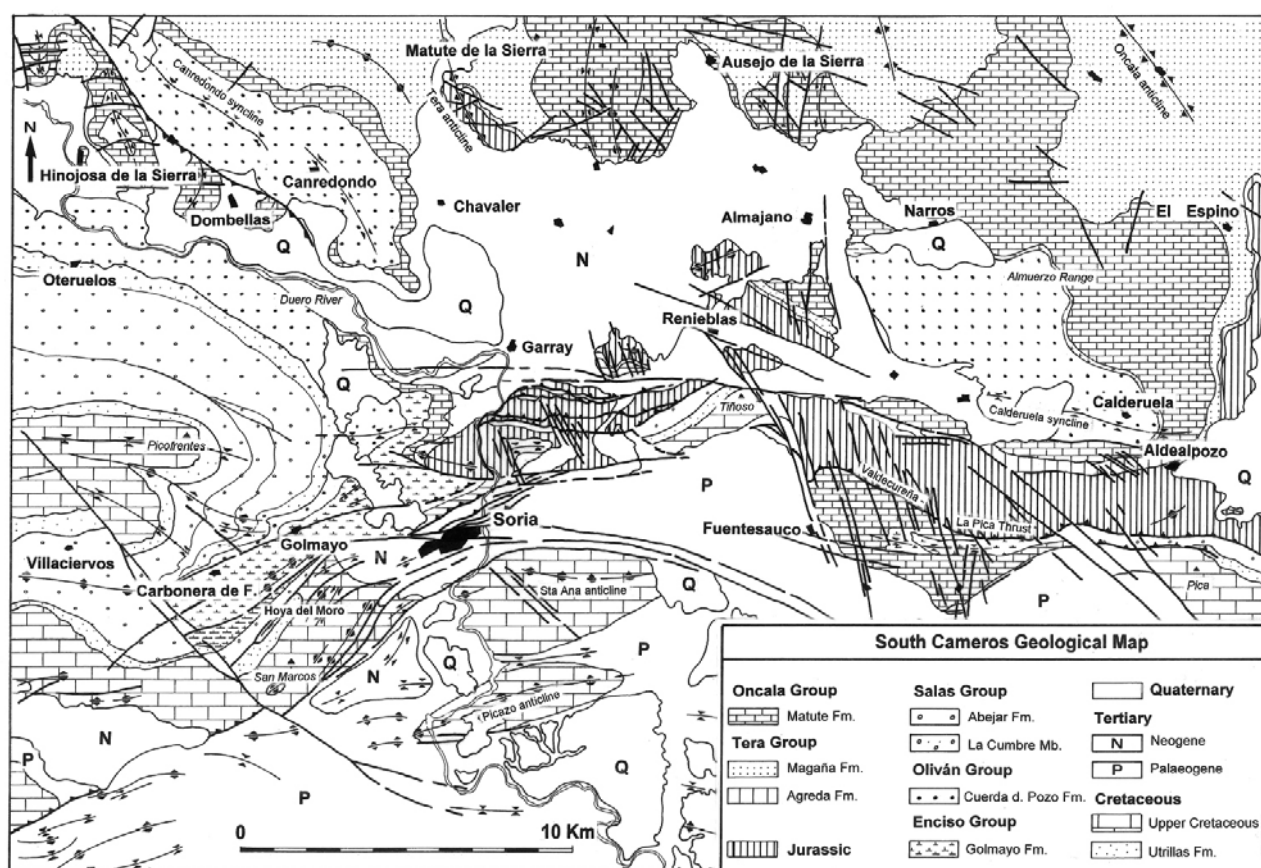


Figure 7.- Detailed geological map of the Soria South-Cameros Sector encompassing part of the SW limb of the Oncala anticline. The Oncala Group is represented by the Matute Formation and unconformable overlaid by the Enciso and Oliván Groups. The tectonic framework and the geology of the Jurassic, Upper Cretaceous and Tertiary are modified after Beltrán Cabrera *et al.* (1980) and Navarro Vázquez *et al.* (1991) and the geology of the Tera and Oncala Groups is modified after Salomon (1982a,b) and Gómez-Fernández and Meléndez (1994a).



Figure 8- Boundary between the Oncala and Urbión Groups in Yanguas, which is located in the SW limb of the Arnedillo syncline. The boundary is a regional unconformity locally delineated by the sharp change between the limestones and marls of the Oncala Group and the fluvial quartzites of the Yanguas Formation and basal part of the Urbión Group.

however, by Schudack and Schudack (2009) indicates an Upper Berriasian-Lower Valanginian age which, according with the authors, is in strong contrast to the views of Salas *et al.* (2001) and Mas *et al.* (2004).

Further up the Urbión Group unconformable overlies the Oncala Group (Figs. 2, 5 and 8). The Urbión Group is approximately 850-1200 m and dominantly composed of fluvial deposits (Figs. 2, 5 and 8). They are punctuated by several units of multi-storied channels of fine-grained conglomerates and quartzites and by thin-laterally discontinuous units of lacustrine siliciclastics forming part of the Yanguas and Valdemadera Formations. The upper boundary of the Group is a key stratigraphic marker: a thin unit -La Vega Formation- dominated by reddish-purple flood plain mudstones and siltstones (Figs. 5 and 9). The sandstones of the Urbión Group are mostly first cycle quartzarenites (Cámara and Durántez, 1981; Ochoa *et al.*, 2007b). The Urbión Group represents the deposits of a very large fluvial system, one or several terminal fans with ephemeral discharges and highly diluted waters.

The Enciso Group, unconformable overlies the Urbión and Oncala Groups and the Cabretón Formation (Fig. 2). It is to up to 2000 m thick. Its lower part is made up of fluvial deposits-described here as Río Mayor (C₁₂ 3Sa unit of Cámara and Durántez, 1981) and Río Cidacos Formations (Figs. 4 and 5). The middle and upper part consist of a large variety of lacustrine/coastal carbonates and evaporites thick to thin-bedded limestones with mud-cracks marls, fine-grained sandstones and siltstones with ripples and hummocky cross stratification (Doublet *et al.*, 2003).

Biostratigraphic data from charophytes and ostracods by Brenner (1976), Guiraud and Seguret (1985), Schudack (1987), Hernández Samaniego *et al.* (1990) Martín-Closas and Alonso (1998) indicate an Upper Hauterivian-Barremian age.

The sandstones are sub-arkoses with K-feldspars and plagioclases (Cámara and Durántez, 1981).

The Group is further characterised by two fossil assemblages one of freshwater and other of marine-brackish environments (Calzada, 1974; Vieira and Aguirrezabala, 1982; Vieira *et al.*, 1984; Aguirrezabala *et al.*, 1985; Mennessier and Calzada, 1989). Following these authors the fresh water assemblage includes the gastropods *Viviparus*, the bivalves *Margaritifera*, *Eliptionids*, *Unios* and *Paludines* the freshwater fishes *Hybodus* sp. and *Lepidotus* sp. in addition to the ichnite tracks of large reptiles. The marine-brackish assemblage

is characterised *Eomiodon cuneatus*, SOWERBY 1816 *Cerithium vidalinum*, VILANOVA 1859, *Glaucania* sp. and *Cassiopidae* (*Paraglaucania Vierai* MENNESSIER and CALZADA 1985, and *Paraglaucania puisagensis*) usually occurring together in thin but extensive (10-25 km) lumachellas.

The Enciso Group represents also a huge (semi-enclosed) coastal lake complex, open towards the north, to the Biscay Bay. This depositional system was rather different than the one represented by the Oncala Group, it was a mixed system with carbonates and siliciclastics, deeper and diluted, partly controlled by biogenic and by physical processes. Following Doublet *et al.* (2003) it represents the deposits of a wave dominated mixed, siliciclastic-carbonate lacustrine system.

The Oliván Group unconformable overlies the Enciso Group, it is to up 2000 m thick and made up of fluvial deposits and consists of two formations Monjía and Robres del Castillo (Figs. 2, 4 and 5; Hernández Samaniego *et al.*, 1990). As described above they are characterised by the differential development of flood plain and channel sandstones where the percentage of channel deposits is higher in the upper formation (Cámara and Durántez, 1981; Hernández Samaniego *et al.*, 1990); moreover the group includes an intercalation of shallow marine carbonates (Mas *et al.*, 2002, 2004). The sandstones are sub-arkoses with K-feldspars and plagioclases (Cámara and Durántez, 1981).



Figure 9- Detail of La Vega Formation in the Río Cidacos section showing its typical facies consisting of flood basin purple mudstones and siltstones interbedded with thin layers of siltstones to fine-grained quartzites.

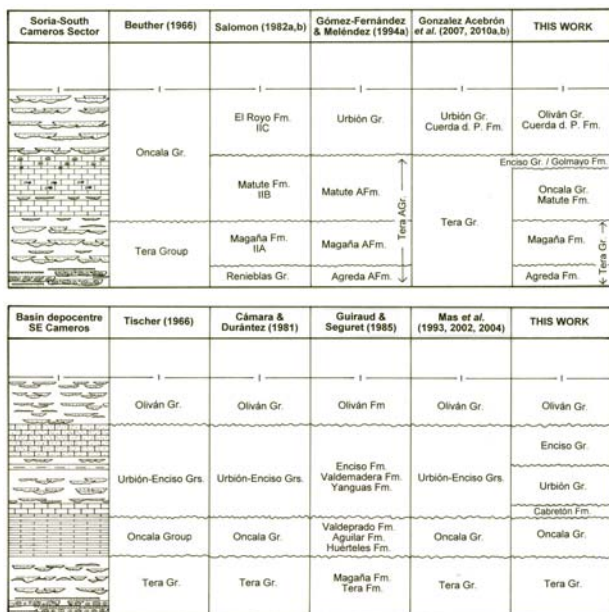


Figure 10.- Comparison between the stratigraphy of previous authors and this work, in the basin depocentre and in the SW limb of the Oncala anticline or Soria-South Cameros Sector.

In the hanging wall of the Turruncún Thrust, the Oliván Group could be represented by the thin unit of shallow marine limestones with oysters studied by Muñoz *et al.* (1997). The Salas Group is also cropping out in NE Cameros, in the hanging wall of the Turruncún Thrust where it is made of fluvial deposits and heterolithic facies with coal (Figs. 2 and 5).

Main changes with respect to previous authors

The above described stratigraphy encompasses few changes with respect to Tischner (1966), Salomon (1982a,b), Guiraud and Seguret (1985), Mas *et al.* (1993, 2002, 2004), Gómez Fernández and Meléndez (1994a), González Acebrón *et al.* (2007, 2010a,b) but very important in order to understand the correlations with Western Cameros. The most significant are the

stratigraphic position and range of the Matute Formation and the discordant character of the Urbión and Enciso Groups (Figs. 5 and 10).

The Matute Formation of Salomon (1982a,b) and Guiraud and Seguret (1985) has a wider stratigraphic range (Renieblas-Almajano section of Martín-Closas, 1989) than it has been previously assumed and represents the overall Oncala Group in the Soria-South Cameros Sector, where it is unconformably overlain by the Enciso and Oliván Groups (Figs. 5, 7 and 10). The (Cervera del) Río Alhama Formation of Salomon (1982) is only correlative with the lowermost part of the Matute Formation (Figs. 5 and 10) and therefore to use the name of Matute to describe the lower genetic sequence of the Oncala Group is incorrect.

The Cabretón Formation is an independent formation of Upper Berriasian-Lower Valanginian age, unconformably overlying and underlying the Oncala, Urbión and Enciso Groups respectively (Fig. 2, 5 and 10). Besides the unconformable relations, the carbonate character and small percentage of terrigenous of the Cabretón Formation are in strong contrast with the highly diluted basin and high supply of terrigenous represented by the Urbión Group (Fig. 5). The carbonate character of the sedimentation is a common fact with the underlying Oncala Group so the largest change in the syn-rift mega-sequence is represented by fluvial deposits of the Urbión Group (Fig. 5).

The boundary between the Urbión and Enciso Groups is not gradational as it has been assumed by most of the authors (Tischner, 1966; Cámara and Durántez, 1981; Salomon, 1982a,b; Guiraud and Seguret, 1985; Mas *et al.*, 1993, 2000, 2004) but marked by a regional unconformity (Figs. 5 and 10). The upper part of the Urbión Group is delineated by La Vega Formation, an extensive unit of flood plain mudstones, which is unconformably overlain by the Enciso Group Río Mayor and Río Cidacos Formations (Figs. 5, and 10).

Review of the Western Cameros Upper Jurassic-Lower Cretaceous Stratigraphy

General characteristics

The characteristics of the syn-rift mega-sequence in Western Cameros have been briefly described in the

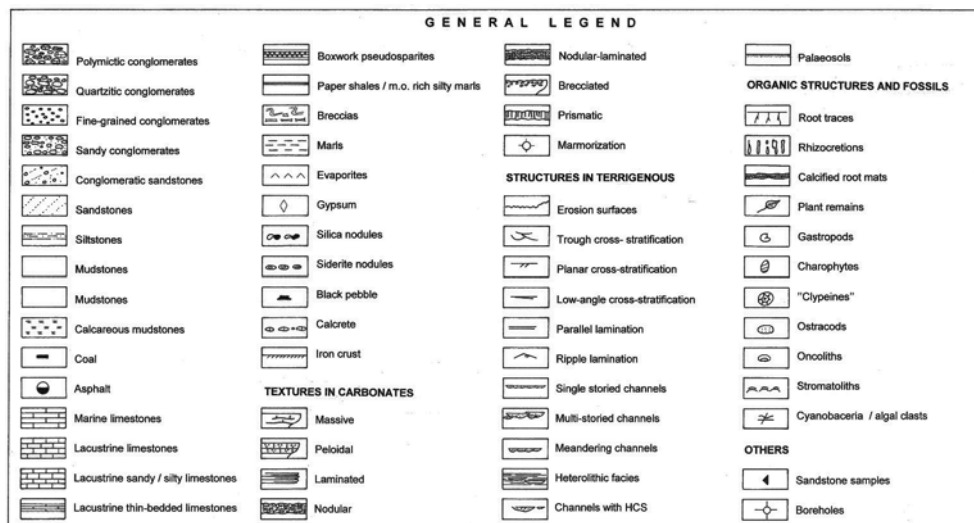


Figure 11. General legend

introduction. In the Western Cameros terrigenous supplied margin, the mega-sequence is much thinner (2500-3000 m) than in the basin depocentre, dominated

in the lower part by a monotonous succession of distal fluvial deposits punctuated in the lower part by thin multi-storied units of channel sandstones and in the upper part by a monotonous succession of proximal – middle fluvial deposits punctuated by several units of quartzitic conglomerates. Further west in the secondary depocentre of NW Cameros the syn-rift mega-sequence is 1000-1300 m thick and its lower part consists of distal fluvial deposits interbedded with lacustrine carbonates and minor evaporites, the upper part is made of distal fluvial deposits. In the adjacent terrigenous starved flexural margins of NW and SW Cameros the thickness is further reduced, the lower part is dominated by thick-bedded palustrine carbonates the upper part by thin units of distal fluvial deposits with calcic palaeosols. Figure 11 encompasses the legend to understand the figures in the sections below.

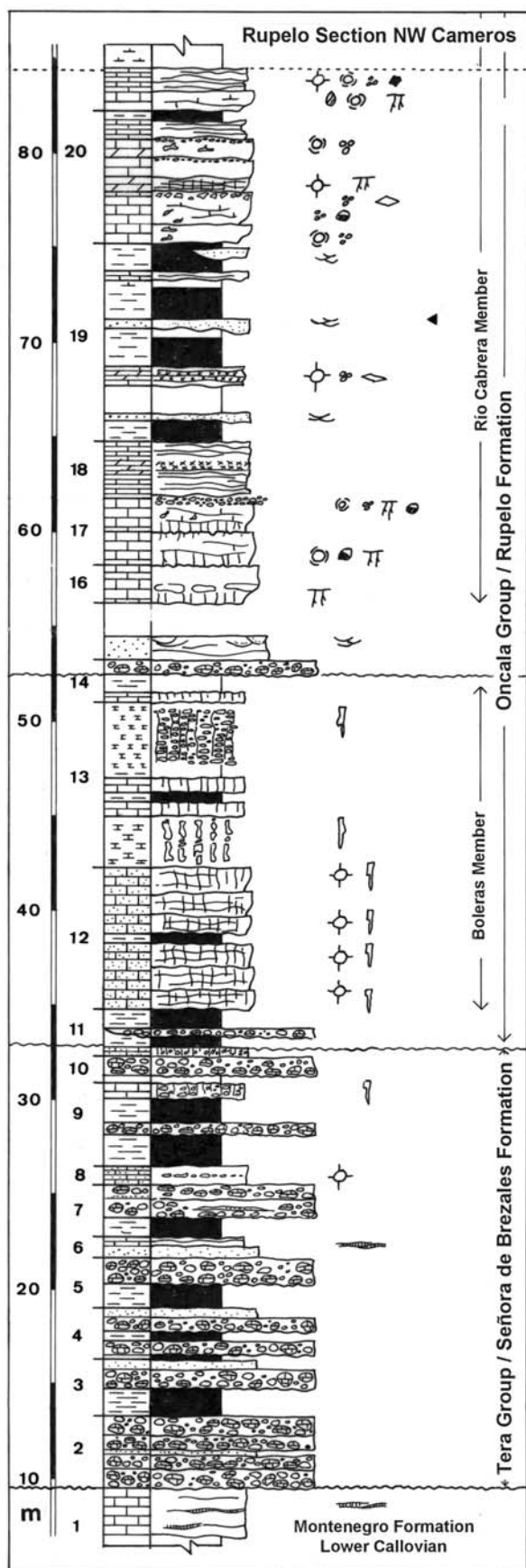
Tera Group

Previous authors: Reviewed after Beuther (1966) to include only the basal limestone clasts conglomerates which have been described as the ‘terrigenous lithosome’ of the Hortezielos and Castrovido Groups by Salomon (1982 a,b) and as the Señora de Brezales Formation of Platt (1989a, 1995). It includes the Agreda Formation of Gómez-Fernández and Meléndez (1994a) and the Magaña Formation of Salomon (1982). However the Tera Group of SE Demanda and of the southern limb of the Picofrentes syncline is not included (Figs. 2 and 7).

Stratigraphy: In large part of Western Cameros, the Tera Group is only represented by the Señora de Brezales Formation (Figs. 5 and 12). In the sector of Soria-South Cameros, the Group encompasses two formations Agreda and Magaña separated by an unconformity (Fig. 5).

Lithology: The Señora de Brezales Formation consists of 50-150 m of strongly calcretised limestone clast conglomerates, channel sandstones and flood basin mudstones (Figs. 5 and 12). It is relatively thin but it has a wide distribution across Western Cameros (Fig. 5). The overlying Magaña Formation makes the bulk of the Group, it is 400-600 m thick and consists of proximal to distal fluvial deposits, and it has a restricted distribution and occurs in the Soria-South Cameros Sector and eastern Cameros basin depocentre (Figs. 2, 3 and 5). The formation wedges out and disappears in the south limb of the Calderuela syncline in the southern limb of the Río Duero anticline (Figs. 2, 5 and 7). The sandstones are sub-arkoses with K-feldspars and plagioclases (Beuther, 1966; Rey de la Rosa and Ribera Navarro, 1981 a,b; González Acebrón *et al.*, 2007, 2010 a,b).

Figure 12.- The Rupelo section is located in the flexural area of NW Cameros (Section 4 in Figure 3). Here the Tera Group is represented by the Señora de Brezales Formation and the Oncala Group by the Rupelo Formation. In addition to lacustrine palustrine limestones the Oncala group also includes thin intercalations of limestone clast-conglomerates, sandstones and flood plain mudstones.



Jaramillo de la Fuente Section NW Cameros

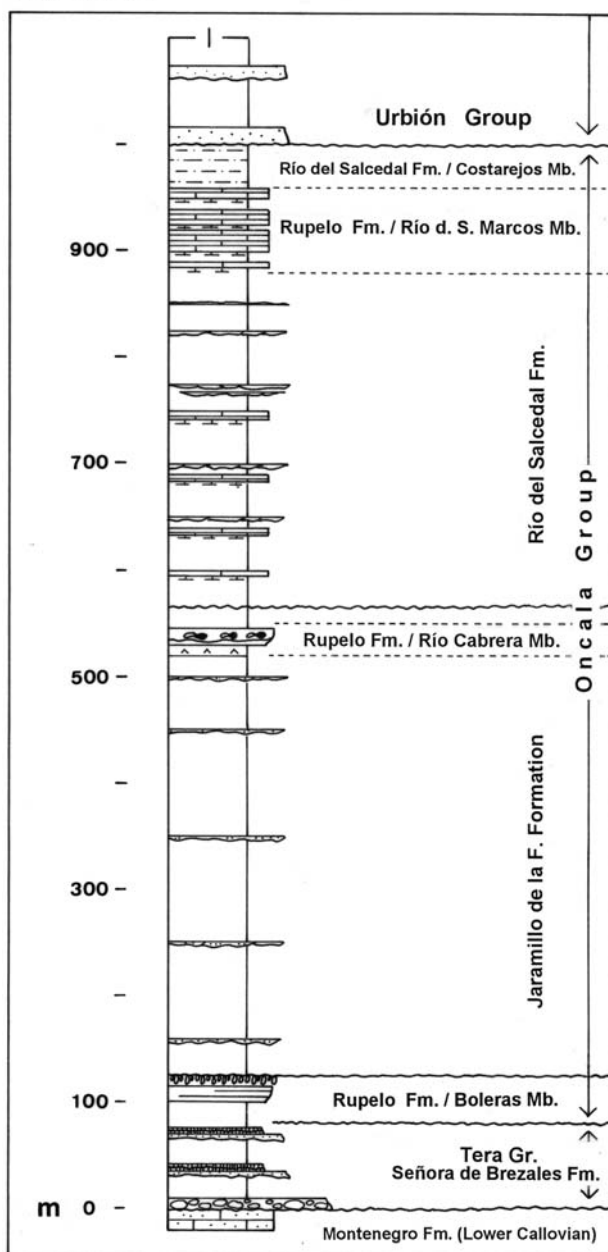


Figure 13.- The Jaramillo de la Fuente Section is located in the NW Cameros secondary depocentre (Section 3 in Figure 3). The section shows the Tera and Oncala Groups and the boundary with the Urbión Group. The Rupelo Formation lacustrine carbonates are interdigitated with the fluvial deposits of Jaramillo de la Fuente, Río del Salcedal Formations.

Distribution: The lower part of the Group- the Señora de Brezales Formation- has a basin wide distribution and the Magaña Formation has a distribution restricted to the SE part of the basin (Fig. 5).

Sedimentary environments: The Señora de Brezales Formation are piedmont deposits (Salomon, 1982ab), strongly calcretised (Mensink and Schudack, 1982; Wright *et al.*, 1988) originated under very low rates of subsidence and sediment supply. The Magaña

Formation represents the deposits of a large fluvial system with a SW-NE proximal distal trend (Gomez-Fernández and Meléndez 1994a).

Boundaries: The Tera Group is unconformable overlying the marine Jurassic and unconformable overlain by the Oncala Group (Figs. 2, 5). Both, the lower and upper boundaries are marked by a sharp lithologic change, the first one by a change from marine limestones to continental conglomerates and the second one by a change from fluvial conglomerates,

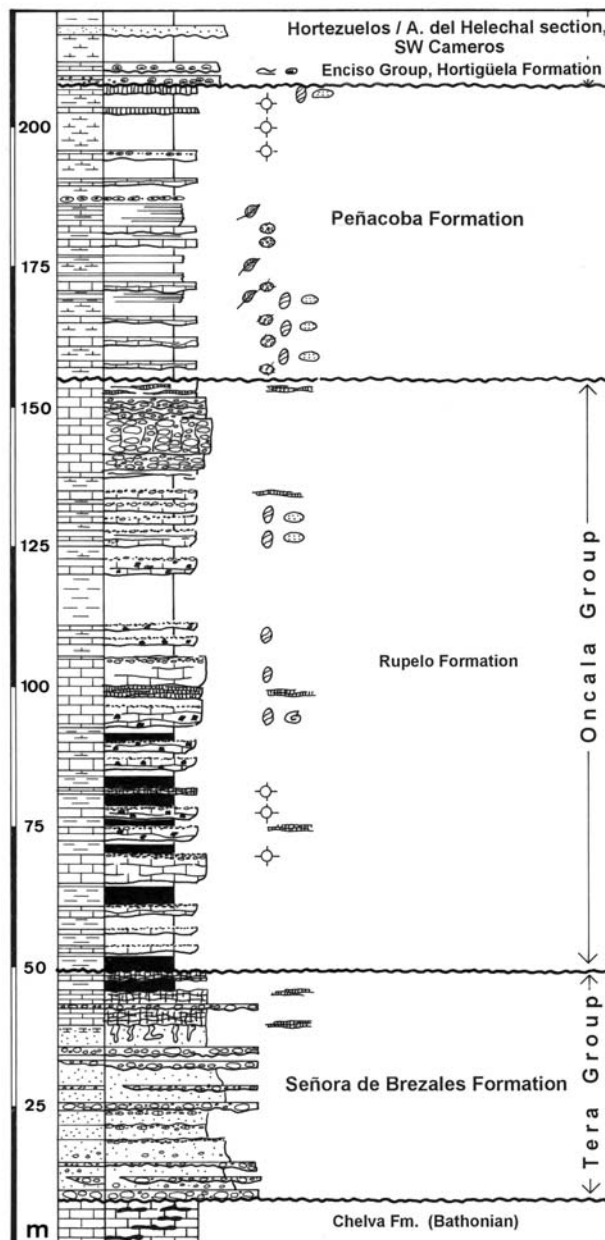


Figure 14.- The Arroyo del Helechal section is located in SW Cameros terrigenous starved margin (Section 39 in Figure 3). The figure illustrates the condensed character of the syn-rift mega-sequence in this sector of the basin. The Tera Group is represented by the Señora de Brezales Formation alluvial conglomerates and upwards follows three lacustrine units, the Oncala Group Rupelo Formation, the independent Peñacoba Formation and the Hortigüela Formation of the Enciso Group. The Urbión Group is absent by non-deposition.

sandstones and siltstones to evaporitic lacustrine carbonates (Figs. 2, 5).

Age: The deposits included in the Señora de Brezales Formation were initially considered of Kimmeridgian-Lower Berriasian age by Salomon (1982a,b), later on, dated with charophytes as Kimmeridgian by Schudack (1987).

Oncala Group

Previous authors: Reviewed after Beuther (1966) to include the lower lacustrine carbonates of the Tera Group and the fluvial deposits of the Tera and Oncala Groups of NW Cameros, South, and SE Demanda. It encompasses the Carbonate unit of the Castrovido and Hortezielos Groups of Salomon (1982a,b), the Rupelo Formation of Platt (1989a,b) the Bolas, Jaramillo de la Fuente, Río del Salcedal, Campolara and Río de San Marcos Formations of Clemente *et al.* (1991), Clemente and Pérez-Arlucéa (1993). The Rupelo Formation has been revised and preserved because it is a well-established name (Platt, 1989 a,c; 1990; 1994a,b; Platt and Wright, 1991, 1992; Platt and Pujalte, 1994) and it makes easy to understand the stratigraphy of the Oncala Group provided that it is equivalent to the Matute Formation in Soria-South Cameros Sector and to the Leza Formation in NE Cameros (Fig. 5).

Lithology: The Jaramillo de la Fuente and Río del Salcedal formations are 50-400 m thick and made of fluvial deposits (Fig. 13). They interfinger and change towards the west and south to the Rupelo Formation (Figs. 13, 14). This formation is 50-350 m thick, its lower-middle part consists of thick-bedded palustrine limestones with scarce flora and fauna, intra-sedimentary evaporites and silica nodules. The upper part is made of thin-bedded dolostones with ostracods and foraminifers, coastal carbonates and palaeosols (Figs. 5, 13 and 14). The sandstones are sub-arkoses with K-feldspars and plagioclases (Arribas *et al.*, 2003).

Distribution and lateral facies changes: The Oncala Group is relatively thick in NW Cameros and South Demanda where it is represented by the Jaramillo de la Fuente, Río del Salcedal formations, which are mainly composed of fluvial deposits (Figs. 5 and 13). The fluvial deposits become thinner progressively dominated by flood plain mudstones towards the N, NW and NE (Fig. 5).

To W and NW the fluvial deposits interfinger with the lacustrine carbonates of the Rupelo Formation (Fig. 13). Further W, in the NW Cameros flexural area, the group, becomes thinner –condensed– consisting of thick-bedded palustrine limestones (Fig. 5). In SW Cameros the Group has similar characteristics; it is represented by the Rupelo Formation, which is thin, condensed and dominantly composed of thick-bedded palustrine and lacustrine/palustrine carbonates (Fig. 14). Towards the basin depocentre the fluvial deposits progressively grade to the thin-bedded limestones, paper shales, marls and evaporites of the Río Alhama, Huérteles and

Valdeprado Formations (Fig. 5). The change takes place by progressively decreasing the percentage of terrigenous (Salomon 1982 a,b).

Towards the Soria-South Cameros sector the fluvial deposits of the Jaramillo de la Fuente and Río del Salcedal Formations interfinger with the lacustrine carbonates of the Matute Formation. The change however is disrupted by the Alpine tectonics (Fig. 2 and 5).

Sedimentary environments: The Rupelo Formation includes successively the deposits of carbonate swamps, evaporitic carbonate lakes and carbonate coastal lakes. The lacustrine-palustrine carbonates were initially studied by Salomon 1982a,b) and later on with more detail by Platt (1989a, 1994a) and Platt and Wright 1991, 1992) whereas the carbonate coastal facies have been described by Clemente (1991). They change towards the Western Cameros Central Sector to the ephemeral fluvial and fluvial dominated coastal plain systems represented by the Jaramillo and Río del Salcedal Formations (Clemente *et al.*, 1991).

Boundaries: The Oncala Group unconformably overlies the Tera Group and the marine Jurassic and it is unconformably overlain, in SW Cameros by the Peñacoba Formation and in the remaining Western Cameros by the Urbión Group (Figs. 2, 5). In NW Cameros the lower boundary is marked by a change from the lithic sandstones of the Señora de Brezales to the quartz feldspathic sandstones with K-feldspars and plagioclases of the Oncala Group (Fig. 12). In SW Cameros the boundary is sharp marked by a change from the limestone clasts conglomerates of the Tera Group to the thick bedded limestones of the Rupelo Formation (Figs. 5 and 14).

Age: The ostracods assemblage from the Rupelo Formation is similar to the Lower Purbeck (Association 1, *Cypridea dunkeri* of ANDERSON 1985) which is equivalent to the lower part of the Lower Berriasian (Julio Rodríguez Lázaro personal written communication). This age agrees with previous biostratigraphic data by Salomon (1982a,b), Schudack (1987), Schudack and Schudack (1989), Martín Closas (1989), Platt and Pujalte (1990) Martín Closas and Alonso (1998) and Schudack and Schudack (2009).

Peñacoba Formation

Previous authors: These are the upper lacustrine limestones of the Tera Group of SW Cameros of Beuther (1966). Described by Salomon (1982a,b) as Formation II or layers with *Clypeina parvula* CAROZZI and correlated with the Hortigüela Formation. Included in the Mambrillas de Lara Member of the Rupelo Formation by Platt (1989a). First described as an independent formation by Clemente *et al.* (1991), Clemente and Pérez-Arlucéa (1993).

Type section: It is located at Arroyo del Helechal, northern limb of the Hortezielos anticline, SW Cameros, in the geological map nº 315 Santo Domingo de Silos (Section 39 in Fig. 3).

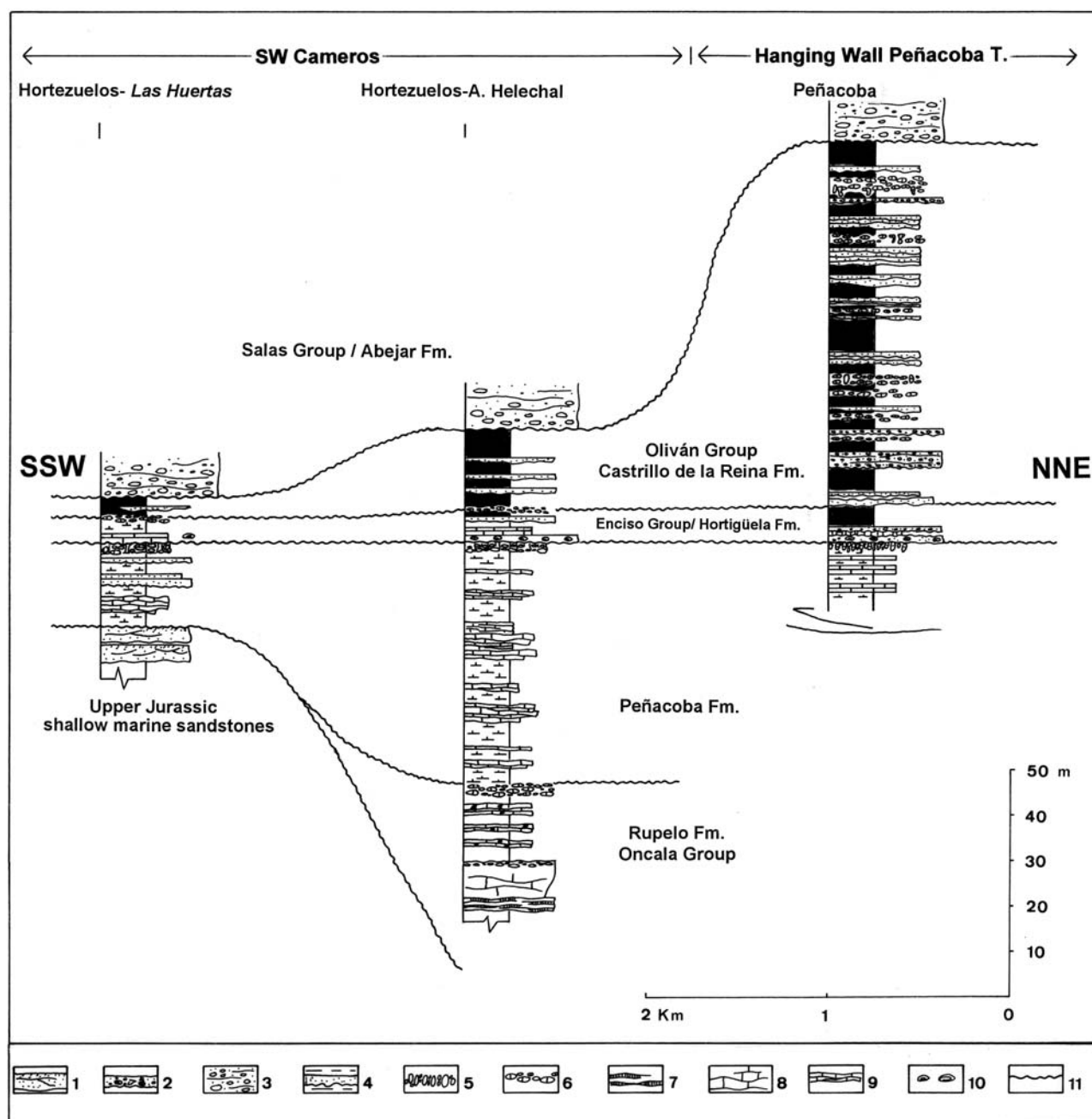


Figure 15.- Cross-correlation panel located in SW Cameros (Sections 38, 39 and 41 in Figure 3). The Oncala Group is represented by the Rupelo Formation. The Peñacoba Formation is unconformable overlying the Oncala Group and the marine Jurassic. The Enciso Group is extremely thin represented by the Hortigüela Formation, the lower unconformity is delineated by a thin unit of polymictic conglomerates. The Oliván and Salas groups consist of fluvial deposits. Legend: 1. Marine sandstones, 2. Polymictic conglomerates, 3. Fluvial sandy conglomerates, 4. Channel sandstones, 5. Carbonates with prismatic structure, 6. Pedogenic calcretes, 7. Calcified root mats, 8. Massive lacustrine/palustrine limestones, 9. Well-bedded biogenic lacustrine limestones consisting of highly fragmented charophytes and 'clypeines', 10. Unconformity boundary.

Lithology: In the type section the formation is 53 metres thick and the dominant facies are ochre marls and marly limestones with a rich flora and fauna of charophytes, ostracods and dinosaur remains (Figs. 14, 15). Intercalated in the lower and middle part there are several channels of ochre limestones. They are 0.5-2.70 m thick and 40-50 metres long, usually with small-scale cross-stratification (Fig. 14). The most characteristic microfacies are packstones of highly fragmented *Clypeina parvula* CAROZZI, ostracods, gastropods and dinosaur bones (Fig. 14). The middle

part is a 15 m thick interval of dark brown paper shales, dark-brown to grey marls, grey-ochre marly limestones with coaly wood debris, charophytes and ostracods (Figs. 14, 15). Intercalated there are several layers of siderite nodules. The upper part consists of marmorized marl and marly limestones intercalated with charophytes-rich limestone beds (Figs. 13 and 14). The formation is topped with a bed of marmorized whitish limestones with prismatic texture and locally with small channel sandstones also deeply marmorized (Figs. 14, 15).

Distribution and lateral facies changes: The Peñacoba Formation occurs in the west part of SW Cameros and it is also present in the Contreras anticline and at the west end of the hanging wall of the San Leonardo Thrust (Figs. 2). Along the northern limb of the Hortezielos anticline, the formation has similar characteristics to the type section. It is 50-60 m thick and dominated by organic matter-rich marls and intraclastic marly limestones, also rich on charophytes, clypeines and ostracods. Intercalated in the marls there are limestone banks 0.8-2 m thick and hundreds of metres long, and consisting of clypeine-dominated packstones in the lower part and charophytes-dominated in the upper part. Interbedded with the marls there are nodular limestone lenses/ layers, cemented with siderite, rich on

macrofauna, including small bivalves, gastropods and fish scales, besides there are charophytes and ostracods.

The middle part is represented here by an interval of black bituminous marls, marly limestones and limestones, which are made up of sandy packstones of cyanobacteria and algal clasts, to mudstones with ostracods and pyrite. Interbedded with the black marls are thin layers of quartz-rich intraclastic limestones.

Towards the southern limb of the Hortezielos anticline, the formation becomes thinner (18-20 m) and consisting of thick-bedded limestone of clypeines and charophytes bearing wackestones (Fig. 14). In the middle part there is an intercalation of whitish, sandstones.

They are recycled quartzarenites, with aeolian quartz grains (Fig. 8; Arribas *et al.*, 2003). Towards the west, in the Hortezielos pericline and in the hanging wall of Peñacoba Thrust, the upper part is made of fine-grained conglomerates and marmorized sandstones with fluid escape structures and dinosaur remains (Fig. 15). The formation wedges out at the western Hortezielos pericline and it is not present at the Tejada anticline (Fig. 2).

Sedimentary environment: The Peñacoba Formation represents the deposits of a marly lake system dominated by biogenic processes. The larger thickness of marls and marly limestones from the northern sections in contraposition with the thick-bedded limestones of the southern sections suggest deposition in a lake with a steep-gradient bench margin and low-energy facies similar to the Littlefield Lake described by Murphy and Wilkinson (1980) and modelled by Platt and Wright (1991). The thick-bedded limestones and sandstones from the southern sections probably represent shallow marginal environments and the dominantly marly and marly limestones from the northern sections represent the deeper open lacustrine basin. The dark ochre coloured paper shales and organic-matter rich marls, marly limestones and limestones from the middle part denote anoxic conditions in the lake floor.

The presence of *Clypeina parvula* CAROZZI in the lower and middle part of the formation probably reflects special environmental conditions. Although with some doubts the algae is currently considered as a dasycladacean by Bassulet *et al.* (1978) and by Adams and Mackenzie (1998). Salomon (1982a,b) thought of *Clypeina parvula* to be indicative of oligohaline waters. Schudack and Schudack (1989) doubted about the environment represented by the layers with *Clypeina parvula*.

The algae are similar to the starred charophytes described by Rossi (1993) in the Tertiary Ager basin of Spain where it occurs in association with *Girvanella* and interpreted as deposited in open environments of coastal lakes. Cypridea dominates the assemblage of ostracods and are also indicative of oligohaline water (Julio Rodríguez-Lázaro, personal written communication).

Boundaries: The Peñacoba Formation unconformable overlies the pre-rift mega-sequence and the Tera and Oncala Groups and it is unconformably overlain by the Enciso Group (Figs. 2 and 5). The lower boundary is

Urbión Section
South Demanda

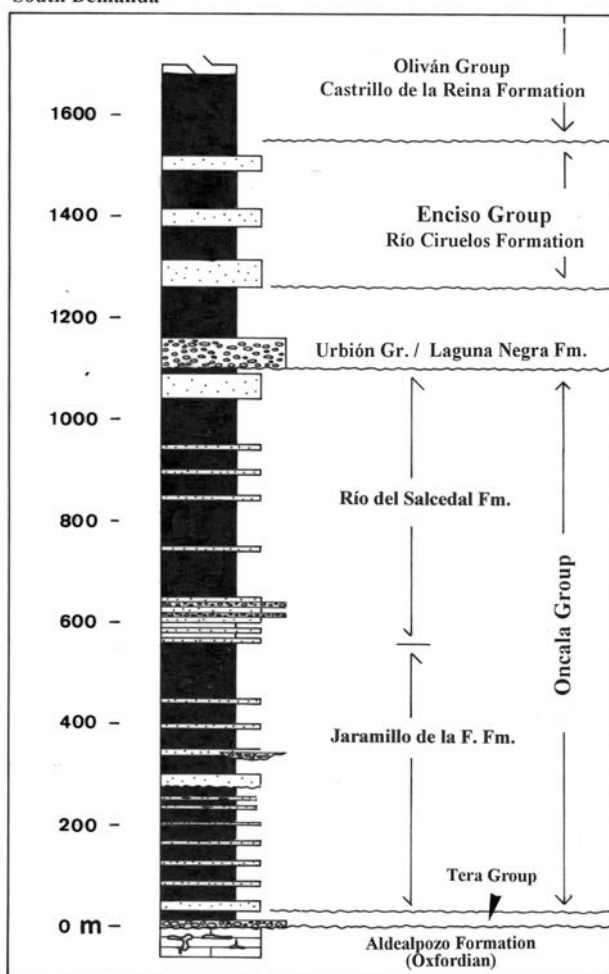


Figure 16.- Urbión section (Section 15 in Fig. 3) showing the stratigraphy of the syn-rift mega-sequence in South Demanda, the middle area of the terrigenous supplied margin. The Tera Group is represented by the Señora de Brezales Formation. The Magaña Formation is absent by non-deposition. The Oncala Group Jaramillo de la Fuente and Río del Salcedal Formations consists of a monotonous succession of middle-distal fluvial deposits punctuated by thin units of multi-storied channel sandstones. The Urbión Group is represented by the Laguna Negra conglomerates, which is the first extensive unit of quartzitic conglomerates in the upper half of the syn-rift mega-sequence.

sharp and marked by an inter-formational palaeosol on top of the Rupelo Formation (Figs. 13 and 14).

Age: The Formation has an Upper Berriasian-Lower Valanginian age (Fig. 5). The ostracod assemblages from the upper part of the Peñacoba, Arroyo de la Mina and El Helechal sections are comparable with those appearing in the Middle Purbeck (Middle-Upper Berriasian) of southern England (Julio Rodríguez Lázaro, personal written communication). This age is consistent with the Berriasian-Valanginian ages proposed by Salomon (1982a) and Schudack (1987). The ostracod assemblage presented by Beuther (1966) was initially attributed to the Upper Tithonian by Kneuper-Haack (1966) and later considered as Berriasian by Brenner and Wiedman (1974) and by Brenner (1976). Detailed biostratigraphy data by Schudack (1987) from the Horteuelos sections shows that the basal and lower part is Berriasian. Upwards, 20 m above the base, the charophyte assemblage defines the Berriasian-Valanginian boundary. Higher up, directly under the Salas Group the charophyte assemblage has Lower Valanginian age. This author re-interpreted some Kneuper-Haack (1966) samples from the upper part of the succession as Lower Valanginian. Martín-Closas (1989) and Martín-Closas and Alonso (1998) favoured a Valanginian-Hauterivian age.

Urbión Group

Previous authors: Reviewed after Beuther (1966) it includes the lower part of the Urbión Group in the northern part of Western Cameros, in South Demanda and NW Cameros. Described as Urbión Formation by Salomon (1982b).

Stratigraphy: In Western Cameros the Group consists of the Laguna Negra Formation (Figs. 5, 16 and 17).

Lithology: The Group is 60-70 m thick and dominantly composed of quartzitic conglomerates dominated by vein quartz and with a minor percentage of light grey fine-grained quartzites and lidites.

Distribution and lateral facies changes: The Urbión Group occurs in NW Cameros and South Demanda / northern limb of the Salas de los Infantes syncline and Quintanar de la Sierra syncline (Figs. 2 and 5). The Group thins out in the northern limb of the Río Duero anticline and it is not present, probably by non-deposition in the Soria-South Cameros sector, hanging wall of the San Leonardo Thrust and SW Cameros (Figs. 2 and 5).

The Group thins out towards the West in the northern limb of the Salas de los Infantes syncline. Conversely towards the east the Group becomes progressively thicker and changes in Eastern Cameros to the Yanguas, Valdemadera and La Vega Formations (Figs. 2 and 5).

Sedimentary environments: The Urbión Group are the deposits of one/several large terminal fans where the Laguna Negra Formation represents the proximal gravely braidplain and the Yanguas, Valdemadera and La Vega Formations are the flood basin distal environments.

Boundaries: The Urbión Group unconformable overlies the Oncala Group (Figures 2, 5, 17). In South Demanda and NW Cameros it overlies the Río del Salcedal Formation, the boundary is sharply delineated by the proximal fluvial conglomerates over distal fluvial channels flood basin mudstones (Fig. 16, 17).

Age: The Urbión Group probably has an Upper Hauterivian age and this age is based on its stratigraphic position overlying the Oncala Group / Peñacoba Formation and underlying the Enciso Group (Figs. 2 and 5).

Laguna Negra Formation

Previous authors: Revised after the Urbión Formation by Salomon (1982a,b). To avoid confusion and to have a homogeneous naming similar to the overlying groups, the Urbión name has been retained for the Group and a new name – Laguna Negra- has been chosen for the formation.



Figure 17.- The upper part of the Urbión Section, South Demanda (Section 15 in Figure 3). The photograph shows the unconformity between the Urbión and Oncala Groups. In the lower part, the Río del Salcedal Formation consist of soft and erodible flood plain mudstones and channel sandstones. Unconformable in the upper part is the Laguna Negra Formation, a tabular unit of vein quartz conglomerates.

Type section: It is located in the Urbión Peak, South Demanda (Section 15, Fig. 3, and Figs. 16 and 17). Due to the accessibility problems, additional reference sections are located at the Laguna Negra and in the Neila lakes, in the Canales de la Sierra geological map, and Río Duero in the Vinuesa geological map (Fig. 3).

Lithology: In the type section the formation is 60 m thick and made up of white to light grey clasts of quartzitic composition, which includes clasts of white quartz and fine-grained light grey to white quartzites. Clasts are rounded and well-sorted cobbles and pebbles (Figs. 17, 18).

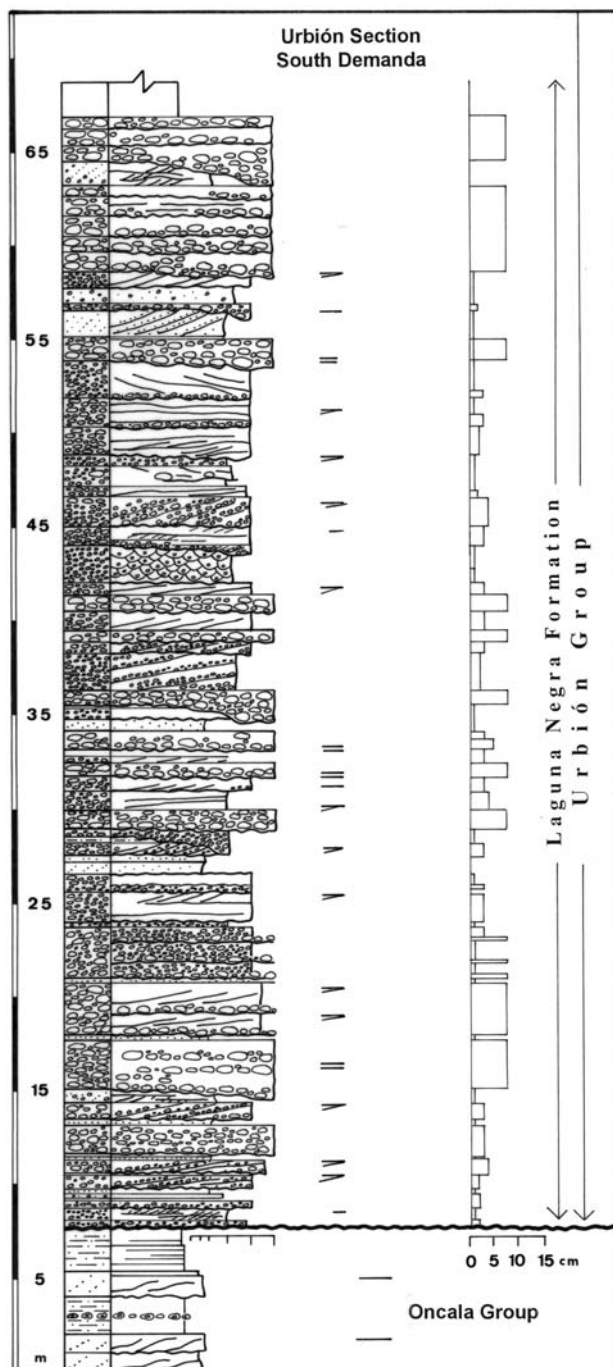


Figure 18.- Laguna Negra Formation quartzitic conglomerates at the Urbión type section. It is a detail of the section illustrated in Figure 16.

The conglomerates consist of quartz (83.3%) and quartzite pebbles (16 %). The percentage of black chert (lidites) is very small (0.63 %). There are three types of quartz pebbles: white milky, rose, and yellow (citrine) and the pebbles of white quartz are the dominant type. There are two main types of quartzites: grey and ochre being the grey quartzites the dominant type (Fig. 19).

In detail, the formation consists of several multi-story units 20-25 m thick separated by thin intercalations of flood plain mudstones or by aeolian sandstones (Figs. 18, 19). Each of the multi-story units is further divided by important erosive surfaces into lower rank units 3-5 m thick. These erosive surfaces usually are overlain by an interval of poly-modal conglomerates dominated by large pebbles and small cobbles (Figs. 18, 19). Upwards the clasts size decreases and they are made of pebble conglomerates to pebbly sandstones. The dominant facies are coupled beds 0.1-0.3 m thick and few tens of meters long of clast-supported, tightly packed poly-modal pebble-cobble conglomerates and thinner layers of fine to coarse-grained sandstones with low angle cross stratification (Figs. 18, 19).

Less frequent are thin (0.1-0.2 m) beds 5-20 m long of pebble -small cobble conglomerates, they are clast-supported and massive with indistinct boundaries or thicker (0.3-0.4 m) beds of matrix supported conglomerates. In the middle upper part of the formation there are isolated thick beds of conglomerates with large-scale cross stratification and positive grading.

Interbedded with the conglomerates there are aeolian sandstones. In the lower part of the formation, they are very thin (several cm) and laterally discontinuous whereas in the middle part they become more important, to 0.2-1.2 m thick, usually single sets, sharply bounded with medium large-scale planar cross stratification (Figs. 18, 19). The lower boundary is horizontal and sharp, the upper boundary is erosive and irregular (Figs. 18, 19).

Distribution and facies changes: The formation occurs with similar characteristics for more than 40 km, parallel to the depositional strike in South and SE Demanda/ in the northern limb of the Quintanar de la Sierra syncline, and northern limb of the Salas de los Infantes syncline (Figs. 2, and 5).

The formation is identified as a 45-60 m thick lithosome of conglomerates in the Quintanar de la Sierra syncline / Neila and Cebollera Range in the southern outcrops of the Río Duero anticline (Figs. 2, 5). It becomes thinner towards the west and south and the percentage of conglomerates decreases, the formation becomes dominated by fine-grained conglomerates and sandstones.

The formation wedges out towards the west, in the northern limb of the Salas de los Infantes syncline, and west of Arroyo de Salas in the northern limb, NW Cameros (Figs. 2 and 5). Towards eastern Cameros, in the Villoslada de Cameros syncline, the formation becomes thicker; it splits out into several lithosomes of pebble conglomerates, pebbly sandstones and sandstones with lateral accretion and separated by intervals of marmorized flood plain mudstones and siltstones. Further west it changes to the Yanguas, Valdemadera and La Vega Formations (Figs. 2 and 5).



Figure 19.- Detail of the Laguna Negra conglomerates paired layers of conglomerates and coarse-grained sandstones from distal sheet floods overlaid by sharply bounded aeolian sandstones with planar stratification.

Sedimentary environment: The Laguna Negra Formation is the deposit of a large gravely braidplain with sheet floods and deposits originated by super-critic flows, draining the basin towards the N, NW and NE. The environments are similar to the alluvial fan of the Roaring River (Blair, 1987) and the Todos Los Santos Formation by Blair (1987). The coupled conglomerates-sandstones with horizontal and low angle lamination are a distinctive feature of sheet floods (Blair and Macpherson, 1994). Conglomerates with low-angle stratification are thought to be the deposits of standing waves or antidunes (Blair and McPherson, 1994). The occurrence of conglomerates with large-scale cross strata, well-developed foresets indicates the presence of deeper incised channels with transverse bars and well-developed slip faces. The sandstones and sandy conglomerates with small scale cross stratification probably are secondary water laid facies originated during periods of alluvial inactivity (Blair and Macpherson, 1994). The coarser clast size of the thin beds of coarse poly-modal conglomerates is thought to be the deposits of incised channel deposits (Blair 1987). The sharply bounded sandstones lenticular to large scale cross stratification are the deposits of aeolian dunes (Wilson, 1973; Clemmensen and Abrahamsen, 1983). The extremely high textural and compositional maturity, the occurrence of aeolian sandstones suggests very low sedimentation rates and multiple erosion-sedimentation events.

Boundaries: The boundary of the La Laguna Negra Formation is the same as the one described above for the Urbión Group (Figs. 2, 5 and 17).

Age: Similar to the Group, the Formation is considered to have an Hauterivian age due to its stratigraphic position overlying the Oncala Group and underlying the Enciso Group (Río Ciruelos and Hortigüela Formation) (Figs. 2 and 5).

Enciso Group

Previous authors: Newly described in Western Cameros to include the upper lacustrine carbonates of the Tera Group in NW Cameros, the lower-middle part of

the Urbión Group in the Western Cameros Central Sector and the fluvio-lacustrine deposits from the Tera Group in the Picofrentes syncline. These deposits have been described by Salomon (1982a,b) as Hortigüela Formation in NW Cameros but with a lower stratigraphic position underlying the Urbión Group and as post-wealdian beds (Salas Group) in SW Cameros.

The correlation of the Hortigüela Formation with the Enciso Group, Cueva de los Juarros and Torrelapaja Formations was first done by Schudack (1987). Nevertheless, the Hortigüela Formation has been systematically reported underlying the Urbión Group by Clemente *et al.* (1991), Clemente and Pérez-Arlucéa (1993), Mas *et al.* (1993, 2002, 2004) and by Salas *et al.* (2001) between others. Detailed mapping however, evidences that it has a higher stratigraphic position and that it overlies the Urbión Group (Figs. 2 and 5 and 21).

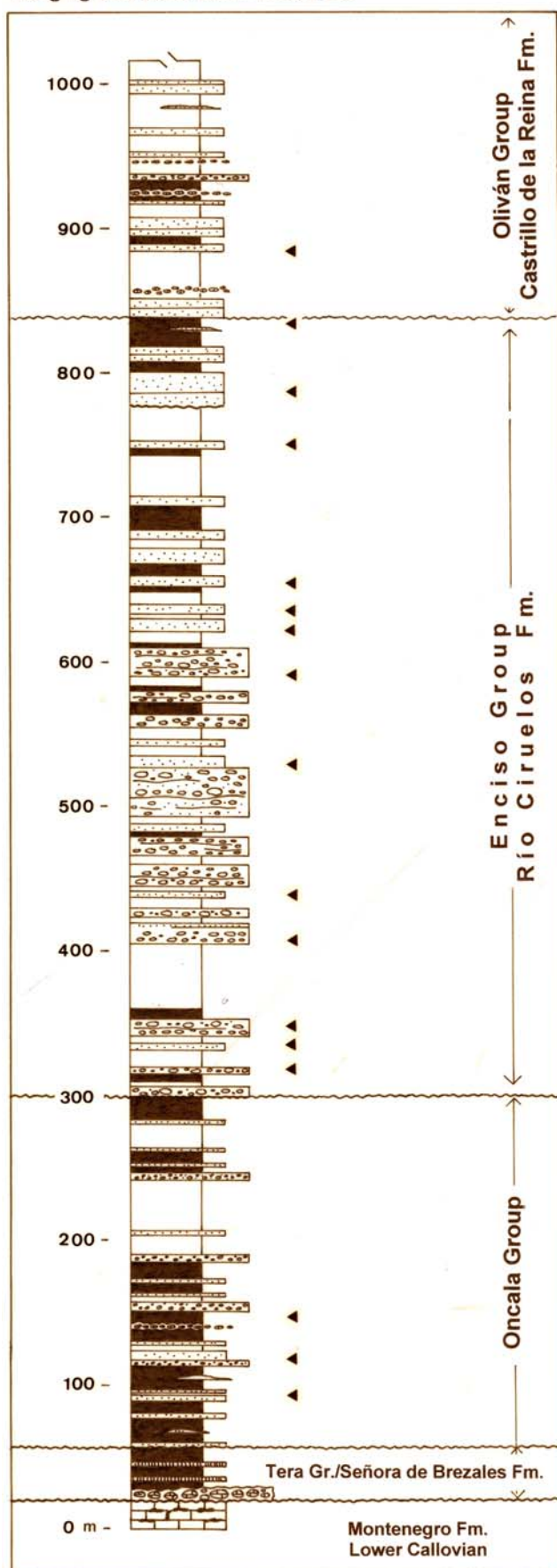
In the southern limb of the Picofrentes syncline, it encompasses the A Unit of Melendez and Vilas (1980) and the Golmayo Formation of Clemente (1988), Clemente *et al.* (1991) and Clemente and Pérez-Arlucéa (1993). Detailed mapping further east, in the Calderuela syncline evidences that the Enciso Group has been included in the uppermost part of the Sierra Matute limestones by Beuther (1966) the Matute Formation of Salomon (1982a,b) and the Alloformation Matute of Gómez-Fernández and Meléndez (1994a) (Figs. 7 and 10).

Stratigraphy: In Western Cameros the Enciso Group is represented by three formations Río Ciruelos, Hortigüela and Golmayo.

Lithology: The Río Ciruelos Formation is 450-500 m thick and dominated by fluvial deposits, multi-storey channel sandstones of pebbly conglomerates and sandstones separated by progressively thicker intervals of flood plain mudstones (Fig. 20). They grade towards the west to the Hortigüela Formation, up to 150 m thick and made up of oncolithic limestones (Fig. 21). In the Soria-South Cameros sector, the Golmayo Formation is several hundred meters thick and consists of a large variety of intra and extra-basinal fluvial deposits, and lacustrine coastal limestones and marls (Fig. 22). In the upper part the formation includes a thin unit of polymictic conglomerates (El Ortegal Member Fig. 22). The formation is characterised by a rich fossil assemblage encompassing cyanobacteria clasts and oncoliths, fresh water bivalves (*Unio* sp); fish scales, gastropods, fresh and brackish water ostracods, charophytes and *Clypeine parvula* CAROZZI. The marly intervals have also yielded a palynomorphs assemblage which includes the marine algae tasmanites (David Batten written personal communication) and remains of large reptiles. The later have been identified by Fuentes Vidarte *et al.* (2005), Pereda-Suberbiola *et al.* (2007) as the ankylosaurian dinosaur *Polacanthus*.

The quartzitic conglomerates of the Río Ciruelos Formation have similar percentage of vein quartz and quartzite clasts. The sandstones of the Río Ciruelos and Hortigüela Formations are sub-arkoses with only K-feldspars (Arribas *et al.*, 2003) whereas the Golmayo Formation sandstones are sub-litharenites with both K-feldspars and plagioclases.

Río Ciruelos Section
Hanging wall block Moncalvillo Fault



Sedimentary environments: The Río Ciruelos Formation is the deposits of a fluvial system with an N, NW and NE proximal-distal trend. Towards the NW and W it changes towards the Hortigüela Formation carbonate lake, partly dominated by biogenic (cyanobacteria) and partly dominated by physical processes.

The Golmayo Formation is the deposit of a fluvial dominated coastal plain, with a SW-NE proximal-distal trend, with diluted carbonate coastal lakes, also partly controlled by the biogenic growth of cyanobacteria and partly by physical processes, waves, water currents and underflows. Moreover it also includes (El Ortégal Conglomerates Member) the deposits of small, basin-fringe fluvial systems.

Distribution and lateral facies changes: The Enciso Group is expansive with respect to the Urbión and Oncala Groups (Figs. 2, 5, 7). The Río Ciruelos Formation proximal-medial fluvial deposits, change towards the west and south to the Hortigüela Formation lacustrine carbonates. In the Soria-South Cameros Sector it consists of medial-distal deposits and lacustrine coastal carbonates. They change towards the basin depocentre to the large wave dominated siliciclastic and carbonate lake represented by the middle-upper part of the group of Doublet *et al.* (2003).

Boundaries. In northern Western Cameros, the Enciso Group unconformably overlies the Urbión Group (Fig. 2) and in the southern part the Peñacoba Formation (Figs. 13 and 14). As it has been described in the first part of the paper, in the Soria- South Cameros Sector it unconformably overlies the Oncala Group Matute Formation (Fig. 7). The Enciso Group is unconformably overlaid by the Oliván Group and in the south basin margin by the Salas Group (Figs. 2 and 5).

Age: Biostratigraphic data from the palynomorphs of the Río Ciruelos and Golmayo Formations indicates respectively a Valaginian-Barremian and a Berriasian-Barremian age (David Batten, written personal communication) and from the ostracods of the Hortigüela Formation indicate an Upper Hauterivian-Lower Barremian age (Julio Rodríguez Lázaro personal written communication). Overall these age determinations agree with previous data by Salomon (1982a,b), Schudack (1987), Martín-Closas (1989) and by Martín-Closas and Alonso (1998).

Oliván Group

Previous authors: Described here as a Group for the first time to include the fluvial deposits that have been

Figure 20.- The Río Ciruelos Section (Section 17 in Figure 3) is located in the hanging wall block of the Moncalvillo Fault, in the proximal-middle areas of the terrigenous supplied margin and further south than the Urbión section. Here, the Tera Group is represented by the Señora de Brezales Formation; the Oncala Group consists of fluvial deposits. The Urbión Group is absent by non-deposition. The Enciso and Oliván Groups are represented by the Río Ciruelos and Castrillo de la Reina Formations respectively. The upper part of the Oliván Group and the Salas Group have been eroded.

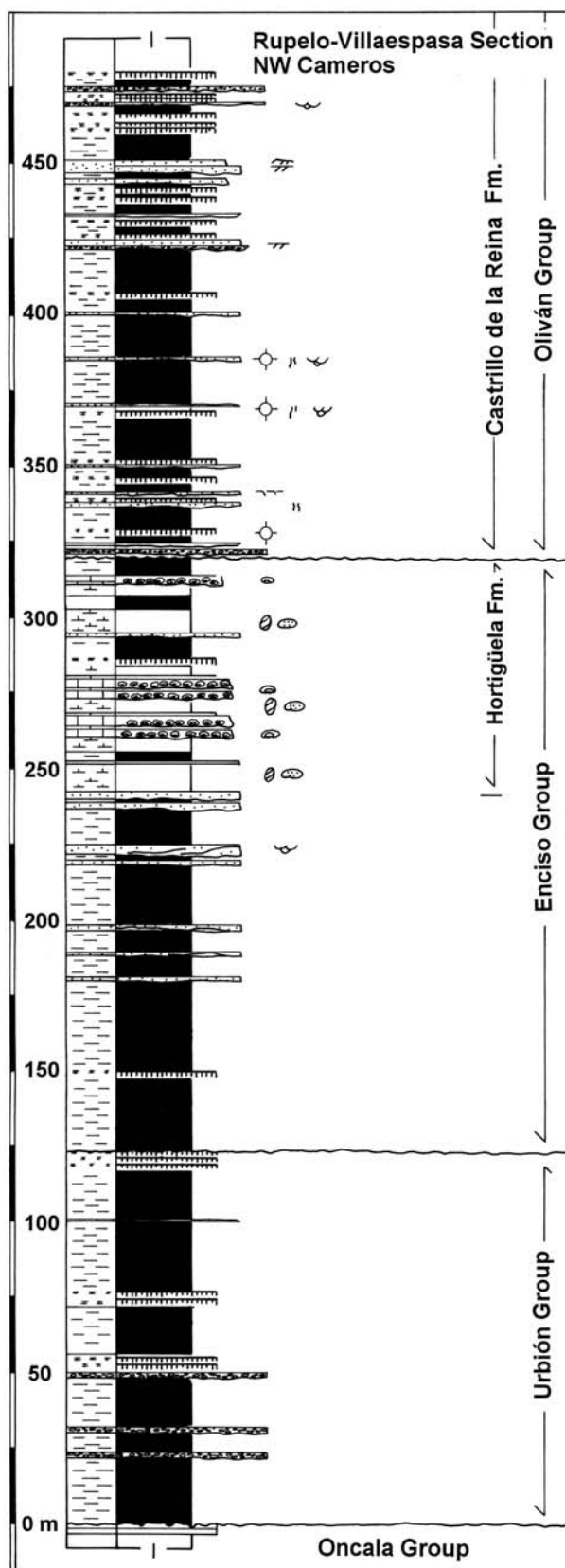


Figure 21. The Rupelo-Villaespasa Section is located in the terrigenous starved flexural margin of NW Cameros (Section 10, Figure 3). The Urbión and Oliván Groups are thin and dominated by distal fluvial deposits, by flood plain mudstones punctuated by numerous pedogenic calcretes. The Enciso Group is also thin, represented by the Hortigüela Formation consisting of fluvial deposits with pedogenic calcretes and oncolithic lacustrine limestones.

previously described by Beuther (1966) in the upper part of the Urbión Group of NW Cameros; in the lower part of the Urbión Group in the hanging wall of the San Leonardo Thrust and in the Oncala Group of the Soria-South Cameros sector.

In NW Cameros the Group basically includes the informal *unit a* of the Urbión Group of Beuther (1966) which is dominated by flood plain mudstones. In the Western Cameros Central Sector (hanging wall of the San Leonardo Thrust) the lower Urbión Group of Beuther is in fact *the third unit of* quartzitic conglomerates in the upper half of the syn-rift mega-sequence. In the Soria-South Cameros sector it includes the fluvial deposits thought by Beuther (1966) to be genetically related with the Oncala Group lacustrine carbonates. These fluvial deposits have been described in the Salas Group by Salomon (1982b) in the Piedrahíta de Muñó Formation by Platt (1989c) in the Cuerda del Pozo (lower-middle part), Castrillo de la Reina and Abejar Formation (*pro part*) by Clemente *et al.* (1991) and the uppermost part of the Golmayo Formation by Clemente and Alonso (1990).

Stratigraphy: The group includes three formations La Gallega, Castrillo de la Reina and Cuerda del Pozo (Figs. 5, 20 to 27).

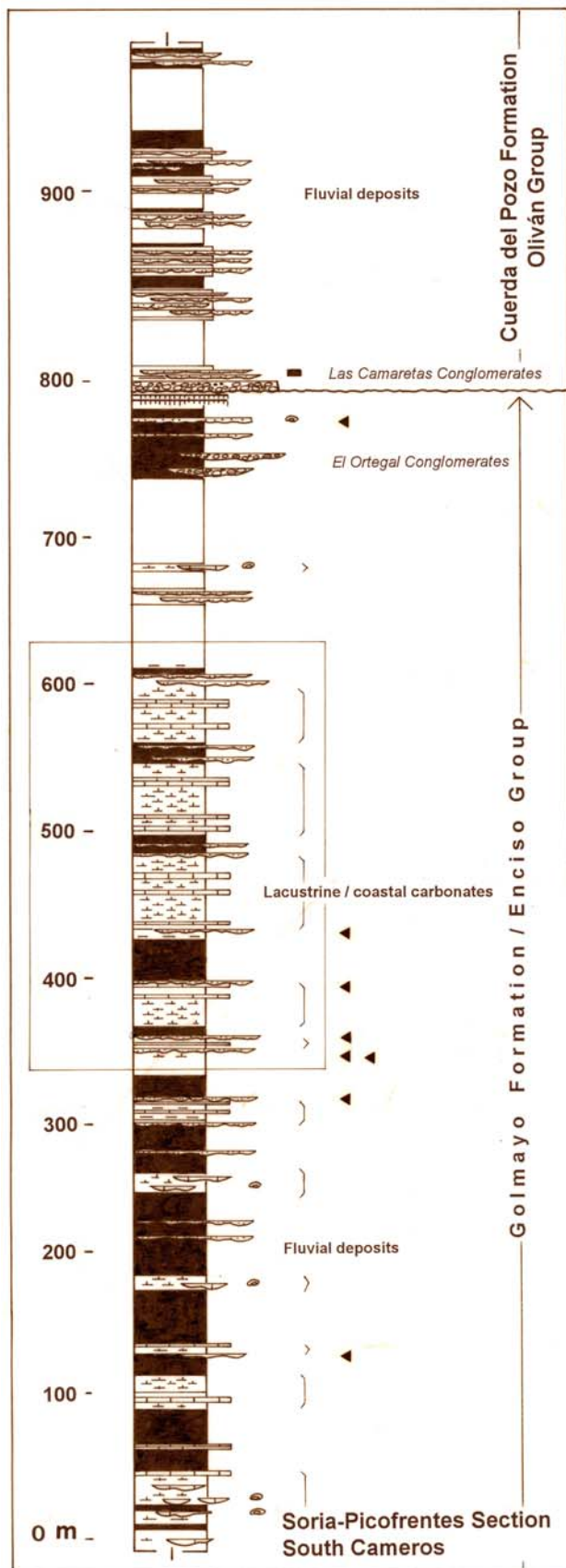
Lithology. La Gallega Formation is 150-200 m thick and the lower-middle part is dominated by sandy pebble-cobble quartzitic conglomerates and conglomeratic sandstones, the upper part of multi-storied channels pebbly conglomerates and sandstones (Fig. 23). Aeolian sandstones and aeolian desert clast pavements are interbedded with the alluvial and fluvial facies (Figs. 23, 24). They represent the proximal facies of the Group in the hanging wall of San Leonardo Thrust. In SW-NW Cameros, the Castrillo de la Reina Formation is 100-600 m thick and with a large percentage of flood plain mudstones (Figs. 5, 20, 21, 22). In SW Cameros the upper part is a thin unit of shallow marine carbonates (El Cauce Member in Fig. 5). In the Soria-South Cameros sector, the Cuerda del Pozo Formation, is 500-550 m thick and made up of thick multi-storied channels of pebbly quartzitic conglomerates separated by thick intervals of flood plain mudstones (Fig. 25) and some channels are topped with aeolian sandstones. In the Picofrentes syncline the basal part of the Group is Las Camaretas Member of the Cuerda del Pozo Formation a thin unit of coarse quartzitic conglomerates (Fig. 22).

La Gallega Formation quartzitic conglomerate has similar percentage of quartzite as of vein quartz, the associated sandstones are sub-arkoses to litharenites with only K-feldspars (Arribas *et al.*, 2003). The sandstones of the Castrillo de la Reina Formation are sub-arkoses with K-feldspars (Arribas *et al.*, 2003) and with K-feldspars and a small percentage of plagioclase feldspars. The sandstones of the Cuerda del Pozo Formation are also sub-arkoses with only K-feldspars (Ochoa *et al.*, 2007b).

Sedimentary environments: The Gallega Formation is the proximal deposit of a large ephemeral gravely braidplain. In NW and SW Cameros the

Castrillo de la Reina Formation is the deposit of the middle-distal fluvial environments of one/several the terminal fans. The Cuerda del Pozo Formation represents the proximal environments of a large terminal fan with channel braided belts. These

proximal fluvial environments have their distal counterparts in the basin depocentre. The frequency of aeolian deposits in the Oliván Group is higher than in previous groups, pointing towards increasing aridity.



Distribution and facies changes: The Oliván Group occurs in large part of Western Cameros and it is extensive with respect to the Enciso Group (Figs. 2, 5). The group occurs in the Western Cameros Central Sector, West end of SW Cameros, NW Cameros, and South Demanda (Figs. 2 and 5). It is also present in the Soria-South Cameros Sector, (southern limb of the Río Duero anticline, Canredondo del Almuerzo synclines, Figs. 2 and 7). The thickness ranges from 550-600 m in the southern limb of the Río Duero anticline Canredondo and Calderuela synclines to 660 m in the secondary depocentre NW Cameros to 150-200 meters in the hanging wall of the San Leonardo Thrust to few tens of meters in SW Cameros (Figs. 2).

Boundaries: The Oliván Group is unconformably overlying the Enciso Group (Figs. 2, 6); in areas of the Soria-South Cameros sector such as the Canredondo syncline where the Enciso Group has been partly eroded, it unconformably overlies the Oncala Group. The Group is unconformably overlain by the Salas Group (Figs. 2, 5, 25, 26).

Age: Probably Aptian, based on the relatively well constrained stratigraphic position of the Castrillo de la Reina and Cuerda del Pozo Formations, unconformable overlying the Hortigüela, Río Ciruelos and Golmayo Formations of the Enciso Group (Figs. 5, 20, 21, 22, 25 and 26).

Salas Group

Previous authors: Revised after Salomon (1982a,b) to include the upper fluvial deposits of the Urbión Group described by Beuther (1966) in the southern part of Western Cameros. These deposits have been previously described as Urgo-Aptian by Palacios (1890), as lower part of the Utrillas Formation by Beltrán Cabrera *et al.* (1980) and as Abejar Group / Formation by Clemente and Alonso (1990), Clemente *et al.* (1991). It also includes the upper part of the Cuerda del Pozo Formation of Clemente and Pérez-Arlucéa (1993) which consists of large, multi-storied channels of conglomeratic feldspathic sandstones. Even though the revised Salas Group only includes the uppermost part of the Castrovido-Salas de los Infantes section chosen by Salomon to illustrate the characteristics of the Group, the Salas name has been

Figure 22. - Lower part of the Soria-Picofrentes section (Section 33 in Figure 3) located in the Soria South-Cameros Sector. Here the middle part of the syn-rift mega-sequence, the Enciso Group is represented by the Golmayo Formation and the Oliván Group by the Cuerda del Pozo Formation. The Golmayo Formation includes in its upper part El Ortegual Member a thin unit of polymictic conglomerates. The Oliván Group basal unconformity is also delineated by Las Camaretas Member, a thin unit of coarse quartzitic conglomerates.



Figure 23.- The Oliván Group La Gallega Formation conglomerates at the type section in the hanging wall of the San Leonardo Thrust, Western Cameros Central Sector and the terrigenous supplied margin. The section has a NW-SE strike and the conglomerates are dipping towards the N. In the lower part is the Río Ciruelos Formation consisting of red flood plain mudstones and small channels of quartzitic conglomerates. They are unconformable overlaid by La Gallega Formation, a tabular unit of quartzitic conglomerates with similar characteristics but different distribution than the Urbión Group Laguna Negra Formation.

preserved because it is a well-established name to describe fluvial deposits stratigraphically younger than the Oliván Group and older than the Utrillas Formation. Biostratigraphic data and stratigraphic position suggest a younger age that indicated by Salomon (1982a,b).

Stratigraphy: The Group encompasses two formations Cabezón de la Sierra and Abejar (Figs. 2, 5). The Cabezón de la Sierra represents the lower –middle part of the Group in the Western Cameros Central Sector and the Abejar Formation the overall Group in the Soria-South Cameros Sector and the middle-upper part of the group in the rest of the basin. To fully understand the stratigraphy of this group further work needs to be done.

Lithology: The Group is best developed in the southern limb of the Río Duero anticline where it is up to 1200 m thick (Fig. 25). Its lower part (300 m) consists of thick multi-storied channels of conglomeratic sandstones with disperse cobbles with large-scale to very large-scale planar and trough cross stratification (Fig. 25). In the middle upper part, intercalated in the sandstones there are up to three units of cobble quartzitic conglomerates with a variety of facies from massive to large-scale planar and trough cross stratification (Fig. 25). Frequently interbedded there are aeolian deposits, mostly sand sheets, sand dunes and desert clasts pavements. The aeolian facies were first described by Rodríguez López *et al.* (2010) in the upper part of the Group. Towards the middle-upper part it includes relatively thick intervals of the facies with



Figure 24.- Aeolian sand sheets in the fluvial channels of the upper part of the La Gallega Formation

inclined heterolithic strata (IHS sensu Thomas *et al.* (1987) and coal of possibly tidal origin (Figs. 25 and 26).

Distribution and lateral facies changes: The Salas Group has been preserved in SW Cameros, in the hanging wall of San Leonardo Thrust, Southern limb of the Río Duero anticline, SW and NW Cameros and eroded in the rest of the basin (Figs. 2 and 26). Detailed correlations west of the Soria-South Cameros Sector are

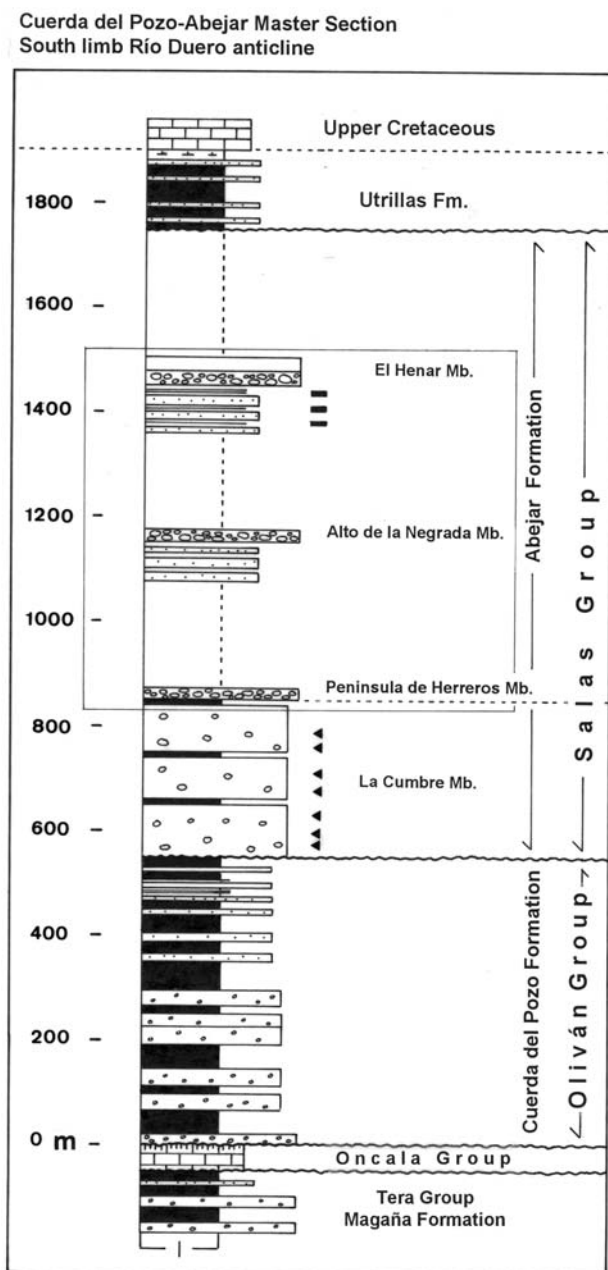


Figure 25.- The Cuerda del Pozo-Abejar Master Section (Sections 30 and 31 in Figure 3) is located in the Soria-South Cameros Sector and in the Southern limb of the Río Duero anticline. Here the lowermost outcrops belong to the Tera Group Magaña Formation, unconformable overlaid by the Oncala Group here represented by the Matute Formation. The Urbión and Enciso Groups are absent by non deposition. The Oliván Group is represented by the Cuerda del Pozo Formation and the Salas Group is fully developed and represented by the Abejar Formation.

uncertain due to poor exposures and extensive forestation. Correlative deposits in Eastern Cameros occur in the hanging wall of the Turruncún Thrust (Figs. 2 and 5).

Sedimentary environments: The Salas Group represents the deposits of an extremely large fluvial

Soria-Picofrentes Master Section
Picofrentes Syncline, South Cameros

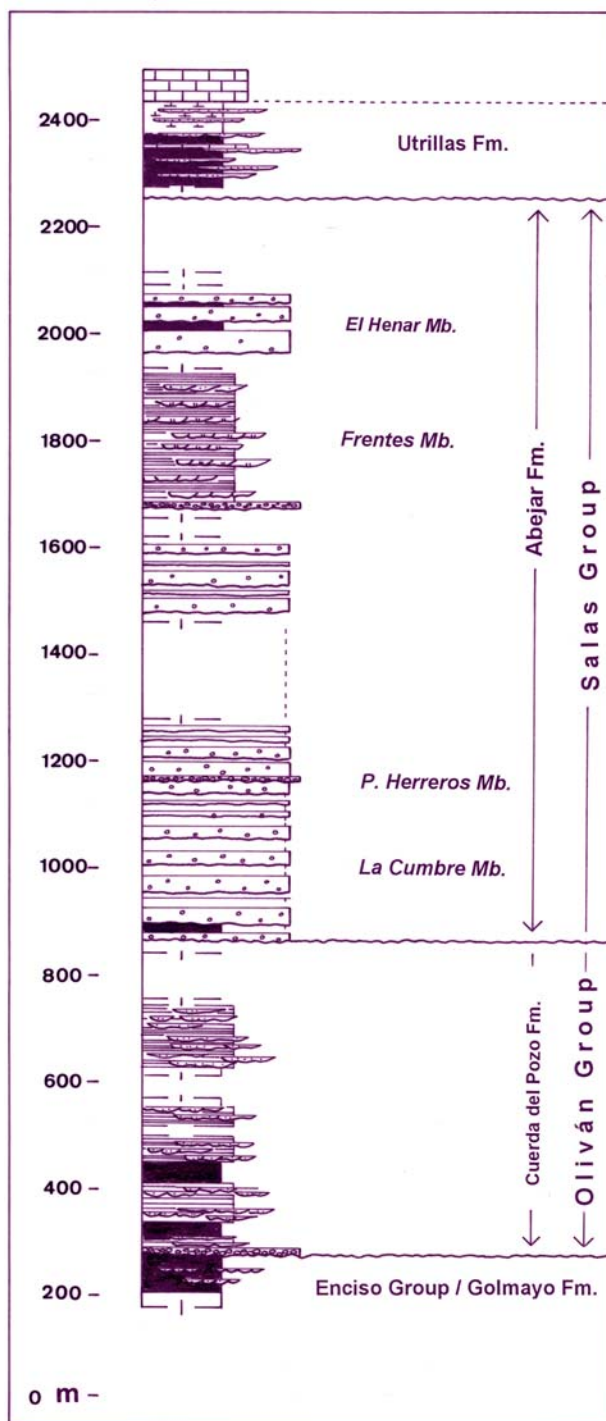


Figure 26.- Middle –upper part of the Soria-Picofrentes Section (Section 33 in Figure 3). Here the upper part of the synrift mega-sequence already includes the Enciso Group and the Oliván Group is represented by the Cuerda del Pozo Formation, the Salas Group is constituted by the Abejar Formation and unconformable overlain by Utrillas Formation.

systems reworked by aeolian processes, draining the basin towards the north, towards the Biscay Bay. As described above, the aeolian deposits were first described by Rodríguez López *et al.* (2010) in the upper part of the group but they also occur in the lower and middle part underlying the coal bearing facies. The large units of conglomerates, conglomeratic sandstones and sandstones probably represent the deposits of fluvial channels with extremely large discharges. The possible tidal origin of the inclined heterolithic strata (IHS) suggest they are the proximal

fluvial environment of a huge coastal tidally influenced plain.

The extremely large percentage of alluvial deposits, the increase in the channel dimensions with respect to the lower groups evidences a large increase in the volume of discharge and an important renovated uplift phase in the Iberian Massif. The presence of aeolian facies point towards a rather arid climate, however the occurrence of coal deposits not only in Cameros but in the remaining Iberian basins evidences high ground water levels. High groundwater levels and water supply from the regional base level during periods of low discharge allow perennial river systems (Nanson *et al.*, 2002). Moreover, a certain degree of chemical weathering is necessary to promote denudation in the drainage basins (Pettijohn *et al.*, 1973; Potter 1978).

The increase in the percentage of aeolian facies and the occurrence of large draas in the upper part of the Group implies a further shift towards aridity as described by Rodríguez-López *et al.* (2009). Similar alluvial and possibly aeolian facies occur in the SW margin of the Asturias basin, in the Vozmediano Formation studied by Jonker (1974). Correlative deposits have been studied by López-Horgue *et al.* (2001) and Martínez de Rituerto-Ibisate and García-Mondejar (2001a,b, 2003a,b) in the SW margin of the Basque-Cantabrian basin and by Rodríguez López *et al.* (2010) in the NW margin of the Maestrazgo basin.

Boundaries: In a large part of Western Cameros the Salas Group unconformably overlies the Oliván Group and in SW Cameros the Peñacoba Formation and the Oncala Group. The Group is unconformably overlain by the Utrillas Formation (Figs. 2, 5, 25 and 26).

The lower boundary is delineated by a sharp change in the lithology and in the sedimentary environment, a change from the fine-grained conglomerates and quartz-feldspathic sandstones and ephemeral channels of the Cuerda del Pozo Formation to the cobble-conglomeratic feldspathic sandstones deposited by a fluvial system with extraordinary large discharges in the Abejar Formation.

Age: Biostratigraphic data – the palynomorph assemblage from samples located in the upper part of the Abejar Formation in the Herreros del Monte in the Soria province, Cabrejas del Pinar Geological map have *Cicatricosisporites* spp. including sub-spherical forms with troughs which are typical from the Barremian-Aptian assemblages (David Batten personal written communication). The stratigraphic position of this Group, however, unconformable overlying the Oliván Group points towards a younger stratigraphic position, probably Aptian-Albian.

Utrillas Formation

Previous authors: It has been studied by Floquet *et al.* (1982), Beuther (1966), Salomon (1982) and Marfil and Gómez Grass (1992). In general is largely equivalent to the Utrillas formation of Beuther (1966) and Salomon (1982a,b). It includes only the *Cauí* unit of Beltran Cabrera *et al.* (1980).

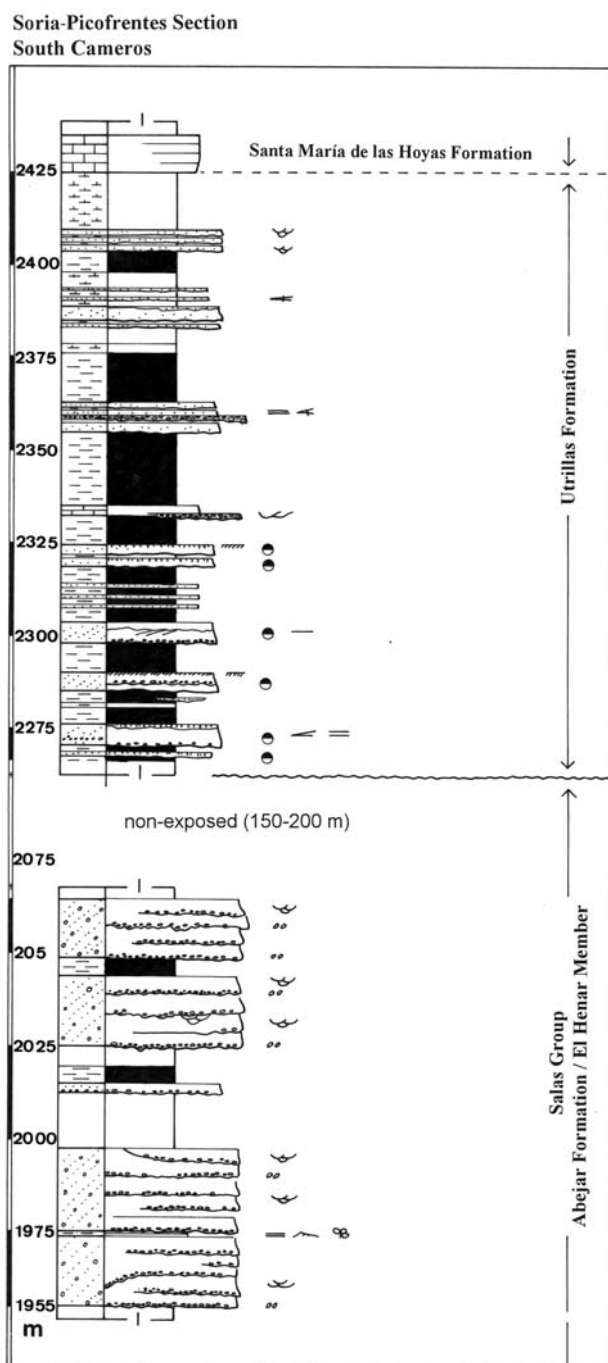


Figure 27.- Detail of the upper part of the Soria-Picofrentes Section (Section 33 in Figure 3) with the upper part of the Abejar Formation, dominated by multi-storied channels of conglomeratic sandstones and Utrillas Formation consisting of an alternation of smaller channel sandstones and flood basin mudstones, marly mudstones and marls.

Reference section: It is located in the Picofrentes syncline, geological map 1:50.000 Cabrejas del Pinar (Figs. 2 and 3). The type area is located in the west margin of the Maestrazgo basin, southeast margin of the Daroca geological map where the Utrillas Formation was formally defined by Aguilar, Ramírez del Pozo and Riba (1971).

Lithology: In the Picofrentes section the formation is up to 160 m thick and its lower part is made up of flood plain mudstones with small channel sandstones grading in the upper part to marly mudstones and marls with intercalations of small channels of carbonate sandstones (Fig. 27). The lower channel sandstones are 5-6 m thick and made up of coarse-grained sandstones and fine-grained conglomerates with scattered pebbles. Grey to dark brown is the most frequent colour due to asphalt impregnations. Channels are multi-storied, with erosive surfaces marked by pebble lags. Sedimentary structures are obscured by diagenesis but in some cases sandstones with low angle lamination and sandstones with large-scale cross stratification are evident. The upper part of the channels is usually made of fine-grained, burrowed sandstones (Fig 27).

In the middle and upper part the channels are relatively small, 2-2.5 m thick and tens of metres wide with large width/thickness (W/T) ratio. The basal part is made of fine-grained conglomerates, upwards the bulk of the channels is made of carbonate (calcite cemented) sandstones and asphaltic, sandstones (Fig. 27). In some cases they are dominated by a single set with large-scale cross-stratification.

The sandstones are arkoses but with only K-feldspars (Marfil and Gómez Grass, 1992). The main differences with respect to the Salas Group are the dominance of sandstones as coarse grained facies, the smaller dimensions of the fluvial channels and the larger percentage of flood basin mudstones and marly mudstones. Although coal may be present it is not a characteristic facies of the Utrillas Formation.

Distribution and lateral facies changes: The Utrillas Formation crops out with similar thickness and characteristics: 150-160 m thick and made flood plain mudstones and marls interbedded with small channel of arkosic sandstones in the south margin of the Cameros basin (Fig. 2).

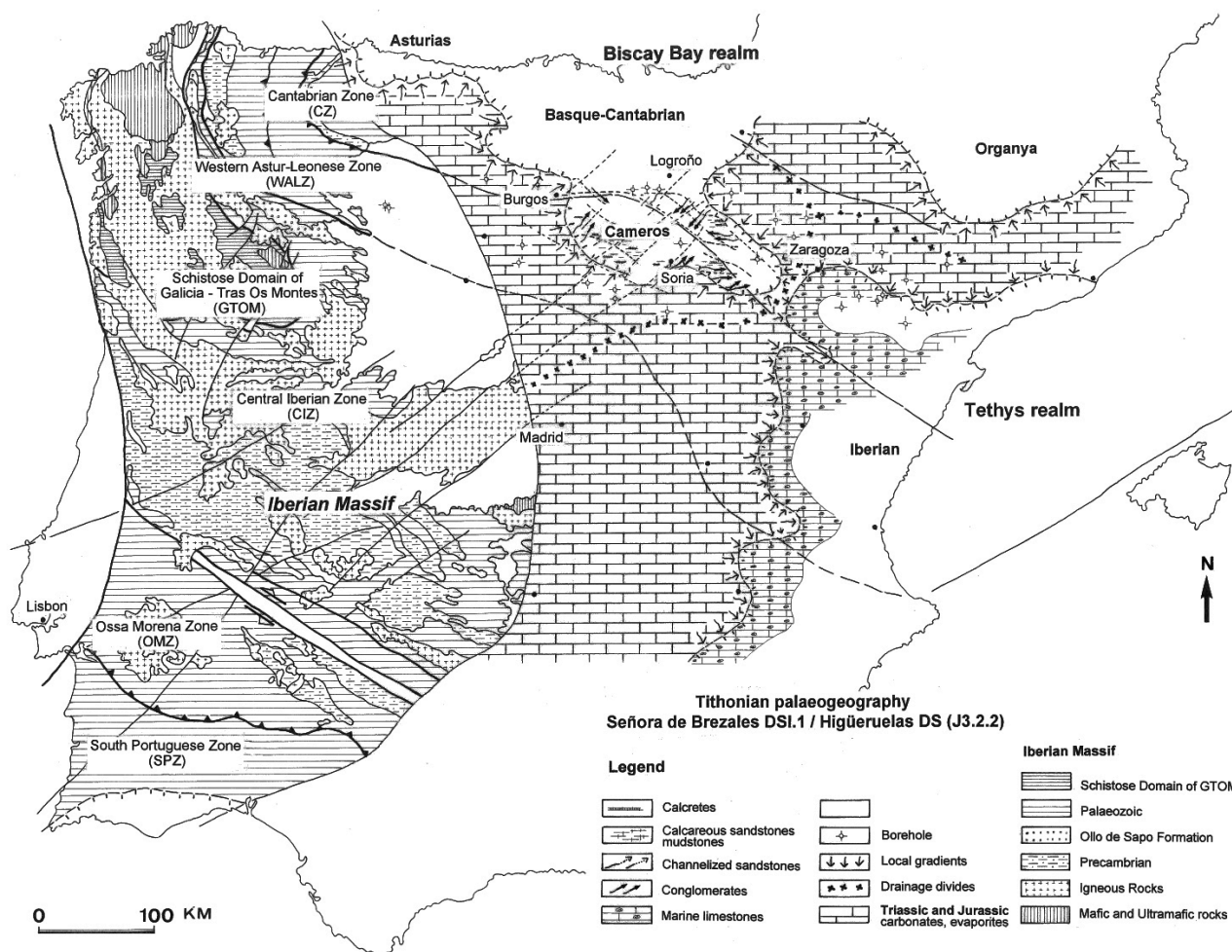


Figure 28.- Palaeogeography of NW Iberia during the Tithonian Lower Berriasian showing the compartmentalization of NE Iberia into the Biscay Bay and Tethys realms. The geology of the Iberian Massif is after Julivert *et al.* (1972), the palaeogeography of the Iberian basin is after Aurell *et al.* (2002). The palaeogeography of the sedimentary cover is delineated by distribution of the Imón, Cortes de Tajuña and Turmiel Formations, which following Goy *et al.* (1976), Goy and Yébenes (1977), López-Gómez *et al.* (1998) and Aurell *et al.* (2002) are the most extensive Upper Triassic and Jurassic units overlapping the Variscan basement.

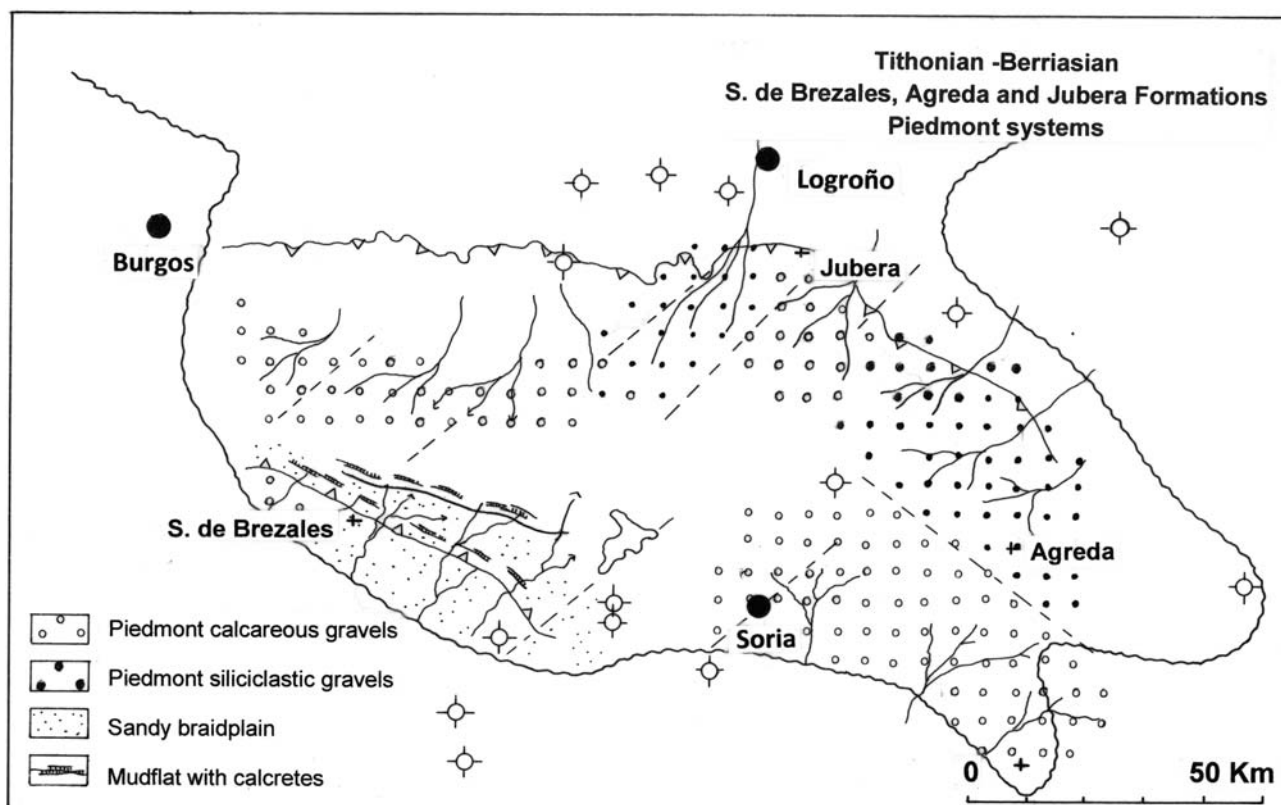


Figure 29.- The Tithonian-Berriasian palaeogeography. The Señora de Brezales, Agreda and Jubera formations are the deposits of a hydrologically closed basin with small piedmont systems (its scale in the figure is exaggerated). The palaeogeography of eastern Cameros is modified after Benke *et al.* (1981).

Sedimentary environment: The Utrillas Formation of Western Cameros probably represents the deposits of distal fluvial to marine marginal environments. Small sandstones bodies probably represent the deposits of fluvial channels. The multi-storied character and burrowing sandstones denote that the bodies represent multiple phases or erosion and deposition.

The facies associations suggest a broad coastal plain with distributary channels. The channel dimensions in comparison with the inferred regional dimensions of the coastal plain were very small. Following Ruiz (1999) who studied the formation in areas located further south of Cameros, the presence of tidal influenced and tidal dominated channels, point towards a coastal plain influenced or dominated by tides which changed basin wards to sedimentary environments dominated by carbonates.

Boundaries: The Utrillas Formation unconformable overlies the Abejar Formation of the Salas Group (Fig. 2). This unconformity has been mapped by Clemente (1987), Clemente and Alonso (1990). The boundary represents a sharp environmental change between fluvial-aeolian quartzitic conglomerates and sandstones of the Salas Group and the coastal plain dominated by flood basin mudstones of the Utrillas Formation (Fig. 27).

Age. The stratigraphic position overlying the Salas Group and the gradual change to the Santa María de las Hoyas Formation point towards an Upper Albian-Lower Cenomanian age (Alonso *et al.*, 1993; Ruiz, 1999; Ruiz and Segura, 1993).

Basin evolution and regional correlation of the main tectono-sedimentary events

The Upper Jurassic-Lower Cretaceous palaeogeography of Iberia has been briefly described in the geological setting. The extensional area was compartmentalized by extensional and transverse faults of NW-SE and NE-SW direction; it included six major depocentres, Asturias, Basque-Cantabrian, and Cameros in the NW, Organya in the NE and the Maestrazgo and the South Iberian Trough in the SE (Figs. 1 and 28). During the Alpine tectonic inversion the Asturias, Basque-Cantabrian and Organya basins were part of the southern Cantabrian-Pyrenees Collisional Front and the Cameros, Maestrazgo basins and the South Iberian Trough were part of the Iberian Ranges (Fig.1). The Cameros and Maestrazgo units are located respectively at the NW and SE ends of the Aragonian Branch (Fig.1).

In the Aragonian Branch, also known as Central Iberia, the Upper Jurassic-Lower Cretaceous syn-rift mega-sequence is absent probably by non-deposition (Gabaldón *et al.*, 1991). Two exceptions are the small basins of Círia in the south (Salomon, 1982; Schudack, 1987; Guimerá *et al.*, 2004) and Aguilón in the north (Soria, 1997; Soria *et al.*, 1995). Complete erosion during the Upper Cretaceous by the fluvial system of the Utrillas Formation is unlikely.

Conversely, north of Cameros, the Upper Jurassic-Lower Cretaceous is present in the footwall of the Cameros Thrust (Lanaja *et al.*, 1987). It is also present further north of Cameros in the sub-surface of the

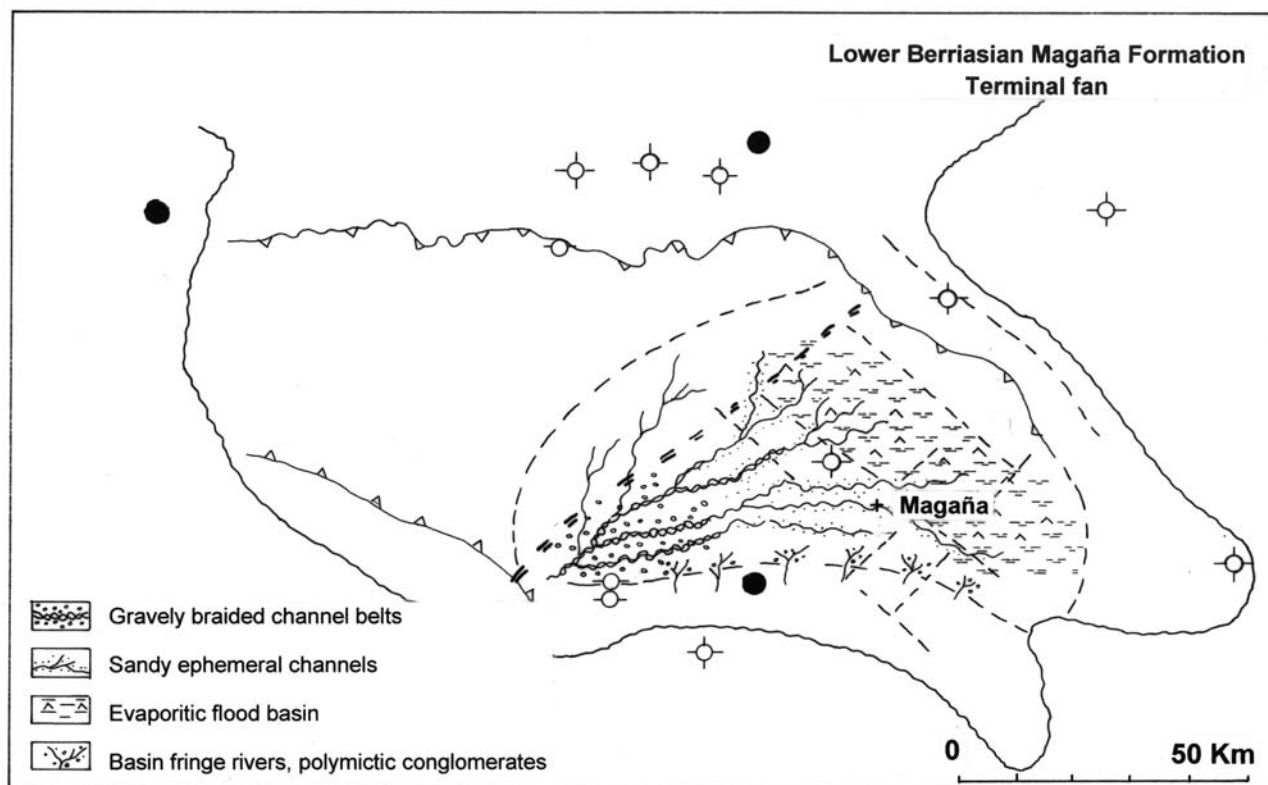


Figure 30. - The Lower Berriasian palaeogeography represented by the Magaña Formation terminal fan with a SW-NE proximal distal trend. It is partly based on Salomon (1982 a,b) and on Gómez-Fernández and Meléndez (1994a).

Montes de Cantabria Thrust (Lanaja *et al.*, 1987). In this area the fluvial and marine marginal deposits correlative with the Salas Group are up to 2000 m thick (Lanaja *et al.*, 1987; Ramírez del Pozo, 1971; García Mondejar, 1989). Therefore, the overall data point towards during the Upper Jurassic-Lower Cretaceous the Cameros basin was palaeogeographically closer to the Basque-Cantabrian than to the Maestrazgo basin (Fig. 1).

Previous accounts of the Cameros basin evolution are from Beuther (1966), Tischler (1966), Salomon (1982 a,b), Guiraud and Seguret (1985), Mas *et al.* (1993, 2002, 2004), Gómez-Fernández and Meléndez (1994) and Salas *et al.* (2001). The basin evolution is based on the stratigraphy and as it has been shown in the previous sections, the present stratigraphy differs considerably from previous authors and so it does the basin evolution and palaeogeography.

During the Upper Jurassic-Lower Cretaceous the Cameros basin underwent eight phases of basin evolution represented by the basal part of the Tera Group, the Magaña Formation, Oncala, Urbión, Enciso, Oliván and Salas Groups and by the two independent formations, Peñacoba and Cabretón (Figs. 28 to 37). The basin stages corresponding to the Tera, Urbión, Oliván and Salas Groups were basin-wide characterised by fluvial sedimentation (Figs. 30,33,35, 36), whereas the basin stages corresponding to the Oncala and the Enciso Groups sedimentation were mostly lacustrine, while the fluvial environments almost restricted to the terrigenous supplied margin (Figs. 31, 34). The basin stage represented by Peñacoba and Cabretón Formations was characterised by lacustrine sedimentation, which in SW Cameros was mostly biogenic (Fig. 32).

The Tithonian-Berriasian piedmont systems and extensive calcretization, basal part of the Tera Group

The basal part of the Tera Group encompasses three formations which are laterally equivalent, the Señora de Brezales Formation in Western Cameros, the Jubera Formation in NE Cameros and the Agreda Formation in the rest of the basin (Figs. 28, 29). These deposits were initially interpreted as piedmont systems by Salomon (1982 a,b) and later on as alluvial fans by Díaz-Martínez (1988), Platt (1995), Gómez-Fernández and Meléndez (1991, 1994a) and Mas *et al.* (1993, 2002 and 2004).

The overall characteristics of these formations: the small volume of conglomerates and the ubiquitous presence of calcretes together with the preservation of the syn-rift mega-sequence at the basin margins point towards a low-relief basin margin, with local uplifts and small piedmont systems (Figs. 28, 29). These environments differ considerably from the typical alluvial fans and fan deltas developed on the footwall of basins with morphological relief and rift shoulders.

Correlative deposits with the basal Tera Group in the Basque-Cantabrian basin are the Saja, Círes and Arroyal Formations of Pujalte (1982 a,b) and of Robles *et al.* (1996); in the Asturias basin with La Ñora Formation of Valenzuela *et al.* (1986) and in the Tethys realm the Higüeruelas Formation of Gómez (1979) and Gómez and Goy (1979), Aurell *et al.* (2002) (Figs. 28, 29). Distinctive characteristics in both realms were the small rates of subsidence and of the terrigenous supply (Fig. 28). Sedimentation continued to be marine in the Iberian basin and changed from marine to continental in the Asturias, Basque-Cantabrian and Cameros basins (Fig.

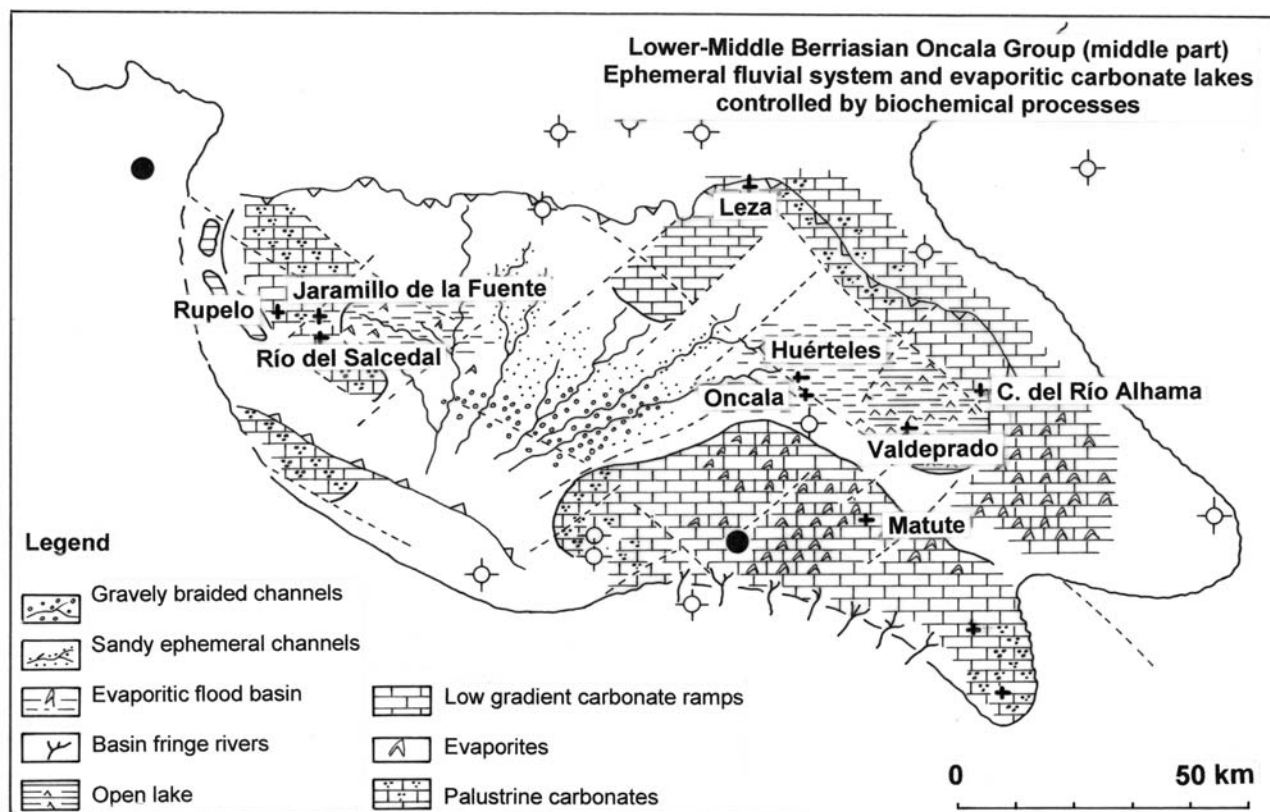


Figure 31.- Palaeogeography of the Lower-Middle Berriasian, represented by the middle and most evaporitic part of the Oncala Group, the Huérteles Formation the upper part of the Jaramillo de la F. Formation and by the middle parts of the Rupelo, Matute and Leza Formations. It is partly based on Salomon (1982a,b) Schudack (1987), Gómez-Fernández and Meléndez (1994a,b), Hernández Samaniego *et al.* (1990), Díaz-Martínez (1988) and Alonso and Mas (1993).

28). This basin stage marks the compartmentalization of NE Iberia into the Biscay Bay and the Tethys realms with a regional drainage divide and two regional gradients one towards the N and NW and another towards the SE (Fig. 28).

The Lower Berriasian terrigenous progradation of the Magaña Formation

The middle-upper part of the Tera Group is the Magaña Formation, the deposits of a terminal fan with a SW-NE proximal distal trend and restricted distribution to Eastern Cameros (Fig. 30).

The Magaña Formation represents the first fluvial progradation from the Iberian Massif since the Triassic. Probably correlative deposits are in the Basque Cantabrian basin, the lower part of the Arcera, Aroco, and Villaró Formations of Pujalte (1982) and in the Iberian basin the lower part of the Villar del Arzobispo Formation of Mas *et al.* (1984), Mas and Alonso (1985) and of Aurell *et al.* (1994).

The Lower-Middle Berriasian evaporitic carbonated lakes of the Oncala Group

The Oncala Group consists of eight formations which are associated by lateral facies changes (Fig. 31). In the Western Cameros Central Sector and SE Demanda the Group is represented by the Jaramillo de la Fuente and Río del Salcedal formations both dominated by fluvial deposits (Fig. 31). They become fine-grained and

more distal towards the N, NW and NE (Fig. 31). They change towards the basin depocentre to three formations, Río Alhama, Huérteles and Valdeprado consisting of open lake basin organic matter-rich paper shales, thin-bedded limestones and evaporites (Fig. 31).

In the flexural margins of NW/SW Cameros, NE Cameros and Soria-South Cameros they change to the thick-bedded palustrine/lacustrine limestones of Rupelo, Leza and Matute formations (Fig. 31).

The basin palaeogeography which can be drawn from the stratigraphy consisted of ephemeral fluvial environments in the Western Cameros Central Sector- the terrigenous supplied margin- and two lake basins a small one in NW/SW Cameros and large one in Eastern Cameros (Fig. 31). Both graded laterally to low-gradient lacustrine ramps shallow lakes and palustrine environments and vegetated wetlands (Fig. 31). These sub-environments configured a facies model of shallow carbonate lakes, highly evaporitic controlled by biochemical processes.

Correlative deposits in the Basque-Cantabrian basin probably are in the Polientes Trough, the Arcera and Aroco Formations of Pujalte (1982b), in the basin depocentre the Villaró (pro-part), shallow marine micro-dolomitic limestones and mudstones, and in the West and East terrigenous starved basin margins the lacustrine carbonates of the Aguilar and Valle de Ata (pro-part) Formations of Pujalte (opus cit.), Caballero *et al.* (1998) and Hernández *et al.* (1990).

Towards the south, time-equivalent deposits in the Iberian basin probably are the middle upper part of the

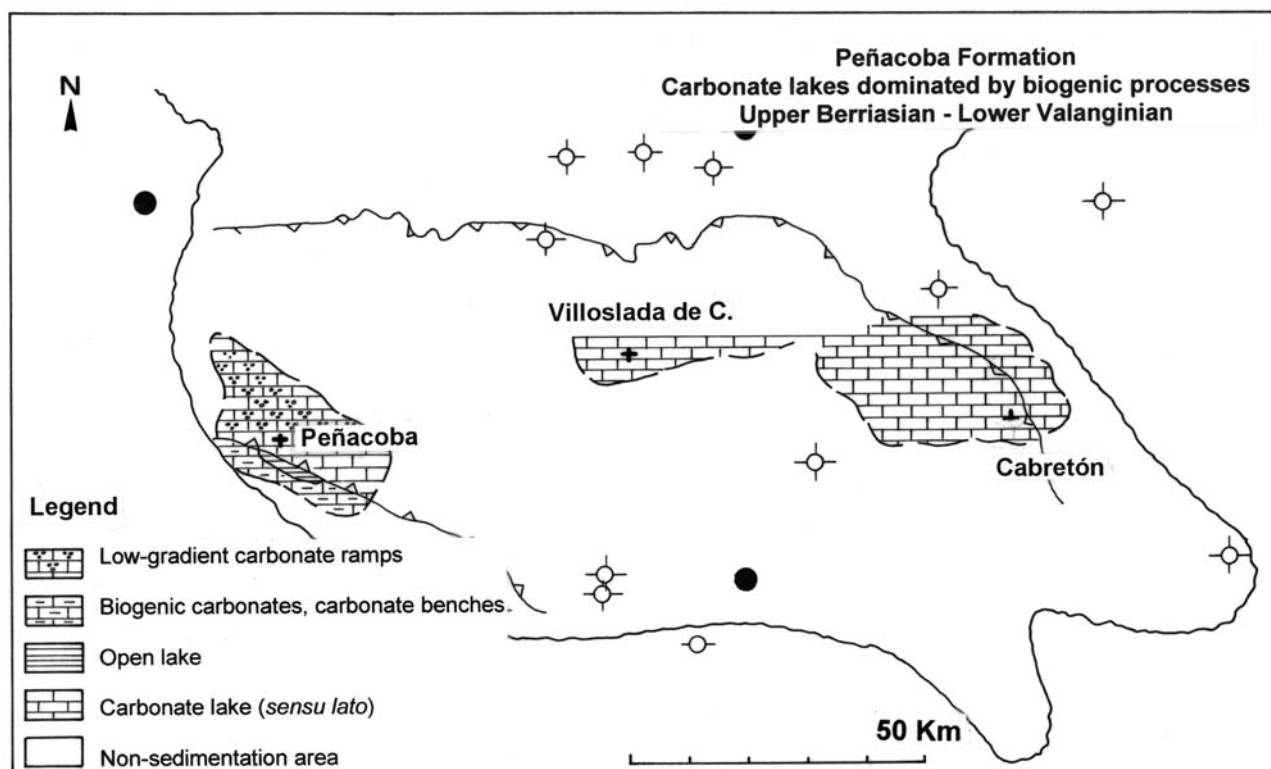


Figure 32.- The Upper Berriasian-Lower Valanginian palaeogeography, represented by the Peñacoba and of the Cabretón formations carbonate lakes developed at the margins of previous basin. The palaeogeography of eastern Cameros is partly based on Durántez *et al.* (1982), Schudack (1987) and Salinas and Mas (1989, 1990).

Villar del Arzobispo, Pleta and Bovalar Formations, that is the middle upper part of the so-called Tithonian-Berriasian super-sequence by Aurell *et al.* (1994), Salas (1989) and by Salas *et al.* (1995, 2001). Following these authors, the basin palaeogeography included in the west basin margin the tidal influenced coastal plain of the Villar del Arzobispo Formation; in the north margin, the extensive carbonate tidal flats of the La Pleta Formation, both coastal plain and tidal flat graded basin wards to the shallow marine environments of the Bovalar Formation.

During this basin stage, Cameros probably evolved from being a hydrologically closed (Río Alhama and Huérteles Formations) to being semi-enclosed and open towards the north (Valdeprado Fm, Upper Leza, Matute and Rupelo formations). The correlative most open environments in the Basque-Cantabrian basin are represented by the Aroco Formation lacustrine-coastal lakes and bays with oysters according with Ramírez del Pozo (1971) and with Pujalte (1982 a,b).

The Upper Berriasian Lower Valanginian biogenic carbonates lakes of the Peñacoba and Cabretón Formations

The Peñacoba and Cabretón are two independent formations and they are the deposits of two small and relatively diluted carbonate lakes (Fig. 32). The Peñacoba Formation carbonate lake was controlled by biogenic processes, by the growth of charophytes and clypeines. The Cabretón Formation is the deposit of a lacustrine basin with tributary channels (Salinas and Mas 1989, 1990). Although it is known that lacustrine

carbonates of this age are also present in SE Demanda (Schudack, 1987; Schudack and Schudack, 2009) the environmental details are unknown (Fig. 32).

The distribution of these deposits in the basin and onlap on the Oncala and Tera Groups and on the pre-rift mega-sequence, evidences a shift of the sedimentation area towards the basin margins (Figs. 31 and 32). Large part of the basin became a non-sedimentation area. The reduced thickness and biogenic character of the lacustrine carbonates point towards very small sedimentation rates and negligent terrigenous supply. SW Cameros was supplied with recycled quartzarenites (Arribas *et al.*, 2003) and there is not data on the provenance of the sandstones in the Cabretón Formation.

Correlative Upper Berriasian-Lower Valanginian deposits in the Basque-Cantabrian basin are largely known to be transgressive (Ramírez de Pozo, 1971; Brenner and Wiedman, 1974; Pujalte, 1982a,b; Salomon, 1982a) with the bryozoan limestones onlapping the basin margin and unconformably overlain by the Utrillas Formation (Ramírez del Pozo, 1971). These transgressive deposits are represented following Ramírez del Pozo (1971) by the limestones with charophytes, brackish ostracods and serpulids, and marls with bryozoans, crinoids and foraminifers of the upper part of the Aguilar section. Moreover the Peñacoba and Cabretón formations are thought to be correlative with the Frontada Formation of Hernández *et al.* (1999), with the Loma Somera and Bárcina de los Montes formations, the middle part of the Villaró Formation and with the upper part of the Valle de Ata Formation of Pujalte (1982b).

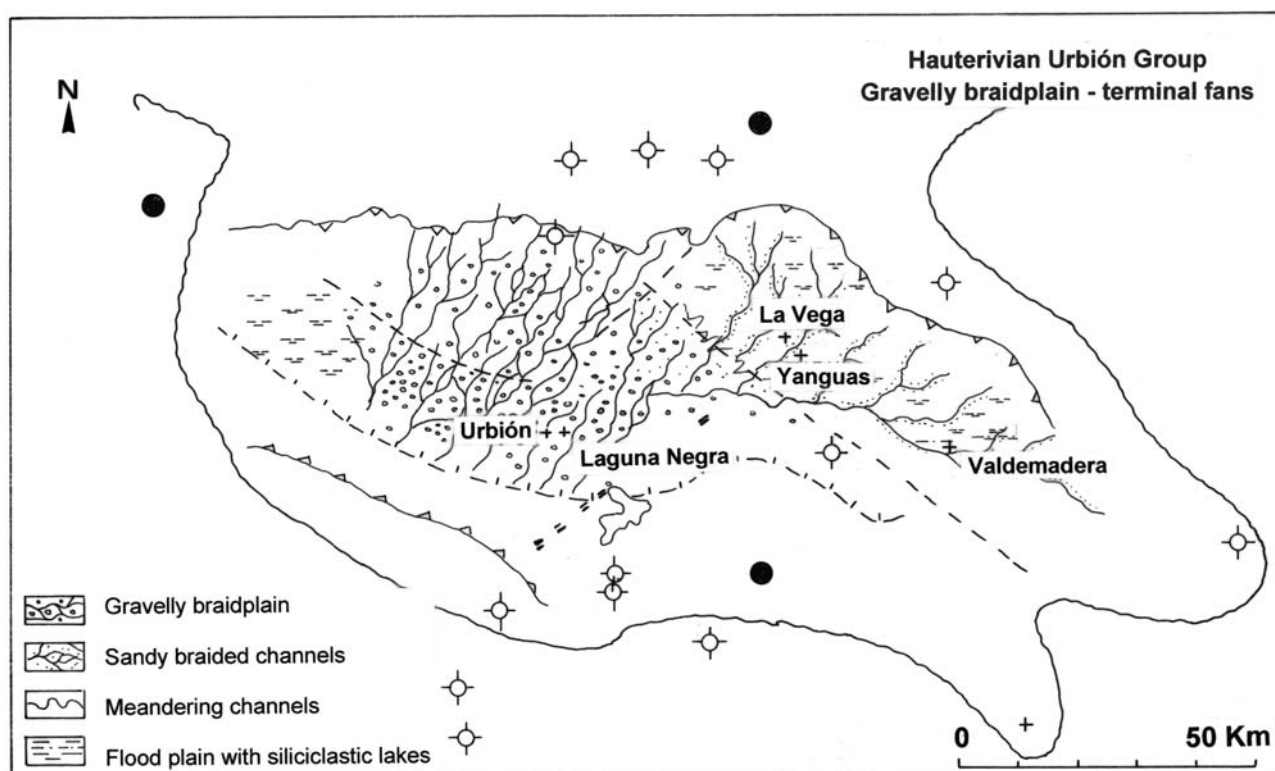


Figure 33.- The Upper Hauterivian palaeogeography represented by Urbión Group: a large fluvial basin encompassing an extensive gravelly braidplain in the SW basin margin and distal flood basin environments in the basin depocentre.

In the Iberian basin this basin stage represented a dramatic change with the compartmentalization of the sedimentation area into two independent basins, the Maestrazgo basin in the north and the South Iberian Trough in the SW which lasted until the Upper Cretaceous (Canerot *et al.*, 1982; Vilas *et al.*, 1992; Salas *et al.*, 1995, 2001). Correlative deposits in the Maestrazgo depocentre are the Ensiroll, Polacos, Mangranés and Bastida Formations of Salas *et al.* (1995).

The restricted distribution of the Peñacoba Formation lacustrine carbonates to SW Cameros implies that they were disconnected from the transgressive shallow marine carbonates of Basque-Cantabria Duero-Ubierna margin described by Ramírez del Pozo (1971). On the other hand, the connexion between the shallow marine environments of the Villaró Formation and the coastal lakes / lagoons with brackish water with a rich fauna of serpulid lumacaella, gastropods and bivalves described by Schudack (1987) in the Valle de Ata Formation with the lacustrine environments of eastern Cameros is uncertain.

The Hauterivian terrigenous progradation of the Urbión Group

The Urbión Group consists of five formations which are associated by lateral or vertical facies changes (Fig. 33). In Western Cameros, the Laguna Negra Formation vein quartz conglomerates are the deposits of a gravelly braidplain which progressively grade towards the basin depocenter in Eastern Cameros to the distal fluvial deposits of the Yanguas, Valdemadera and La Vega Formations (Fig. 33). They

are the deposits of an extremely large and highly diluted fluvial basin (Fig. 33).

Across NE Iberia, this basin stage appears to have been characterised by an important terrigenous progradation and a dramatic change with respect to the previous carbonate sedimentation and lacustrine basins. Correlative deposits in the margins of the Basque-Cantabrian basin are the fluvial Bárcena Mayor Formation of Pujalte (1981, 1982b) up to 600 m thick. In the terrigenous supplied margin of the Maestrazgo basin this basin stage could be represented by the fluvial deposits of the Mora Formation and by the lacustrine Castellar Formation. Correlative deposits in the basin depocentre probably are the Hauterivian shallow marine sandstones of Canerot (1974) later described as Llácova and Avella Formations by Salas (1989), Salas *et al.* (1995, 2001). Further south, in the South Iberian Trough, time equivalent deposits could be the multi-storied fluvial channels described by Mas *et al.* (1982), Vilas *et al.* (1982) in the lower part of El Collado Formation.

The volume of fluvial deposits in the basins of the Biscay Bay realm, in the Basque Cantabrian and Cameros basins is much larger than in the basins of the Tethys realm, in Maestrazgo basin and in the South Iberian Trough, pointing towards differential rates of uplift and of terrigenous supply from the Iberian Massif.

The Upper Hauterivian-Barremian diluted carbonate lakes of the Enciso Group

The Enciso Group consists of five formations: Río Ciruelos, Hortigüela, Golmayo, Río Mayor and Río Cidacos laterally associated to the upper lacustrine/

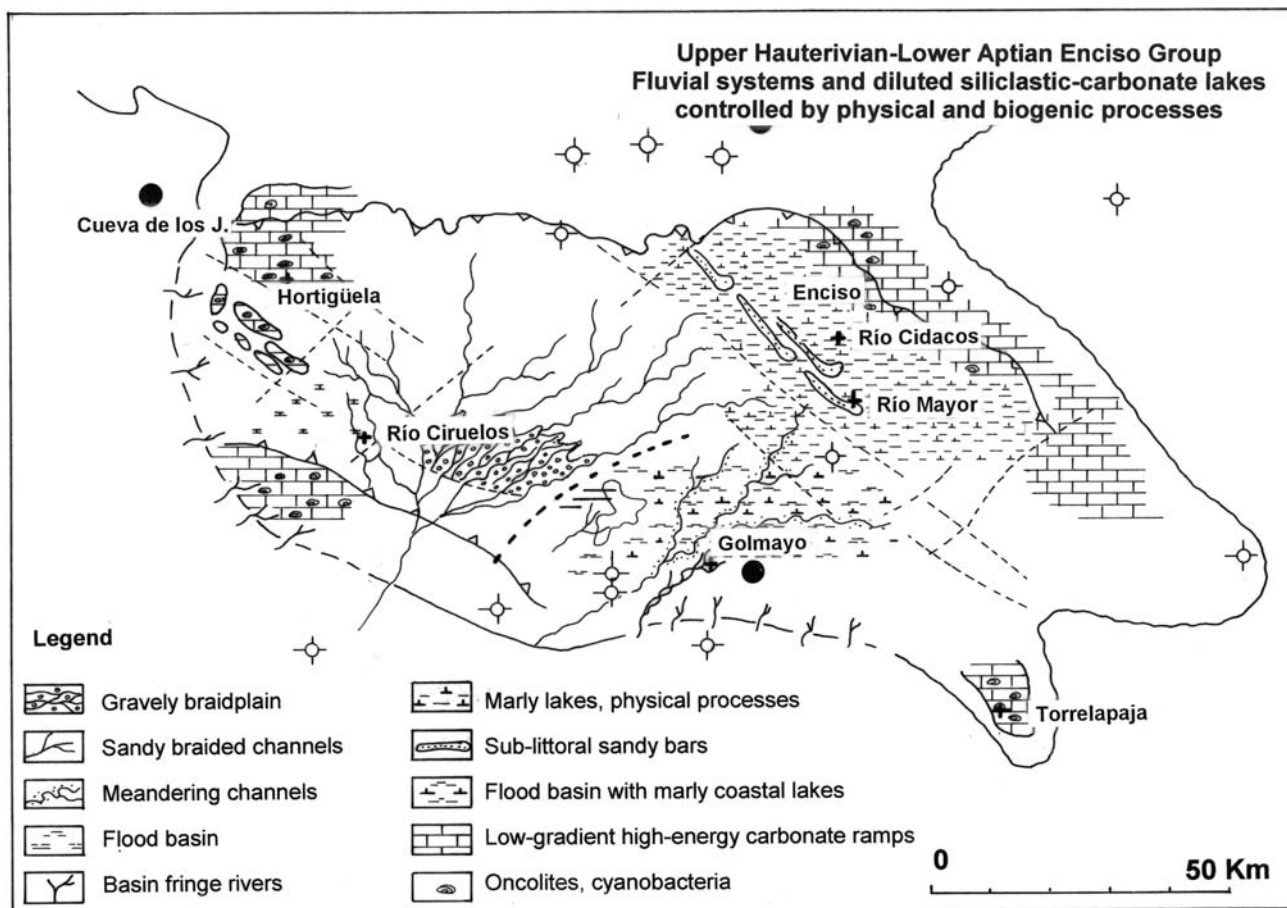


Figure 34.- The Upper Hauterivian-Barremian palaeogeography represented by the Enciso Group: a semi-enclosed, strongly compartmentalized basin open towards the north, almost basin wide with carbonate-siliciclastic fresh water and coastal lakes. The fluvial environments of Río Ciruelos and Golmayo initially reached the basin depocentre and later on they were restricted to the terrigenous supplied margin.

coastal carbonates and siliciclastics of the Enciso Group (Fig. 34). The Group displays similar distribution in the basin and similar lateral changes in thickness and lithology than the Oncala Group (Figs. 32 and 34). In the Western Cameros Central Sector it is represented by the Río Ciruelos Formation; in NW/SW Cameros by the Hortigüela Formation and in the Soria-South Cameros Sector by the Golmayo Formation (Fig. 34). In the basin depocentre the lower part of the Group are the fluvial dominated Río Mayor and Río Cidacos Formations and the upper part are the lacustrine-coastal carbonates and siliciclastics of the Enciso Group (Fig. 34).

The different mineralogical composition of the sandstones and directions of sediment transport indicate that they represent the deposits of two independent fluvial systems: a large one –Río Ciruelos– in Western Cameros Central Sector and a small one–Golmayo– in the Soria-South Cameros sector (Fig. 34). They changed towards NW/SW Cameros to a small carbonate lake– the Hortigüela Formation and towards a larger one with siliciclastics and carbonates in the basin depocentre represented by the upper part of the group (Fig. 34).

The distribution of sedimentary environments, directions of sediment transport and marine-brackish fossil assemblages point towards the group represents a semi-enclosed basin open towards the north with

deeper and more diluted lakes than the ones represented by Oncala Group (Figs. 32 and 34). This was a mixed depositional system with siliciclastics and carbonates, partly dominated by physical processes, by waves (Doublet *et al.*, 2003) and partly dominated by biogenic processes (cyanobacteria) (Fig. 34).

Most of the Iberian basins display common characteristics with the Cameros basin, high rates of terrigenous supply; lacustrine systems dominated by physical processes, coupled with the extensive growth of cyanobacteria. In the marine realms the first development of the rudists bearing Urgonian platforms took place (Vilas *et al.*, 1982 a,b).

Correlative deposits in the Basque-Cantabrian basin probably are the Vega de Pas, Pino de la Bureba and La Lastra Formations and in the basin depocentre the upper part of the Villaró de Pujalte (1982b). In the Círia basin correlative deposits are the fresh water lakes of the Torrelapaja Formation (Fig. 34; Schudack 1987); in the South Iberian Trough the middle-upper fluvial deposits of El Collado Formation and the lacustrine carbonates of la Huérgina Formation of Monty and Mas (1981), Mas *et al.* (1982), Vilas *et al.* (1982), Gomez-Fernández and Meléndez (1991) and Fregenal and Meléndez (1993). In the terrigenous supplied margin of the Maestrazgo basin equivalent deposits probably are the fluvial deposits of the

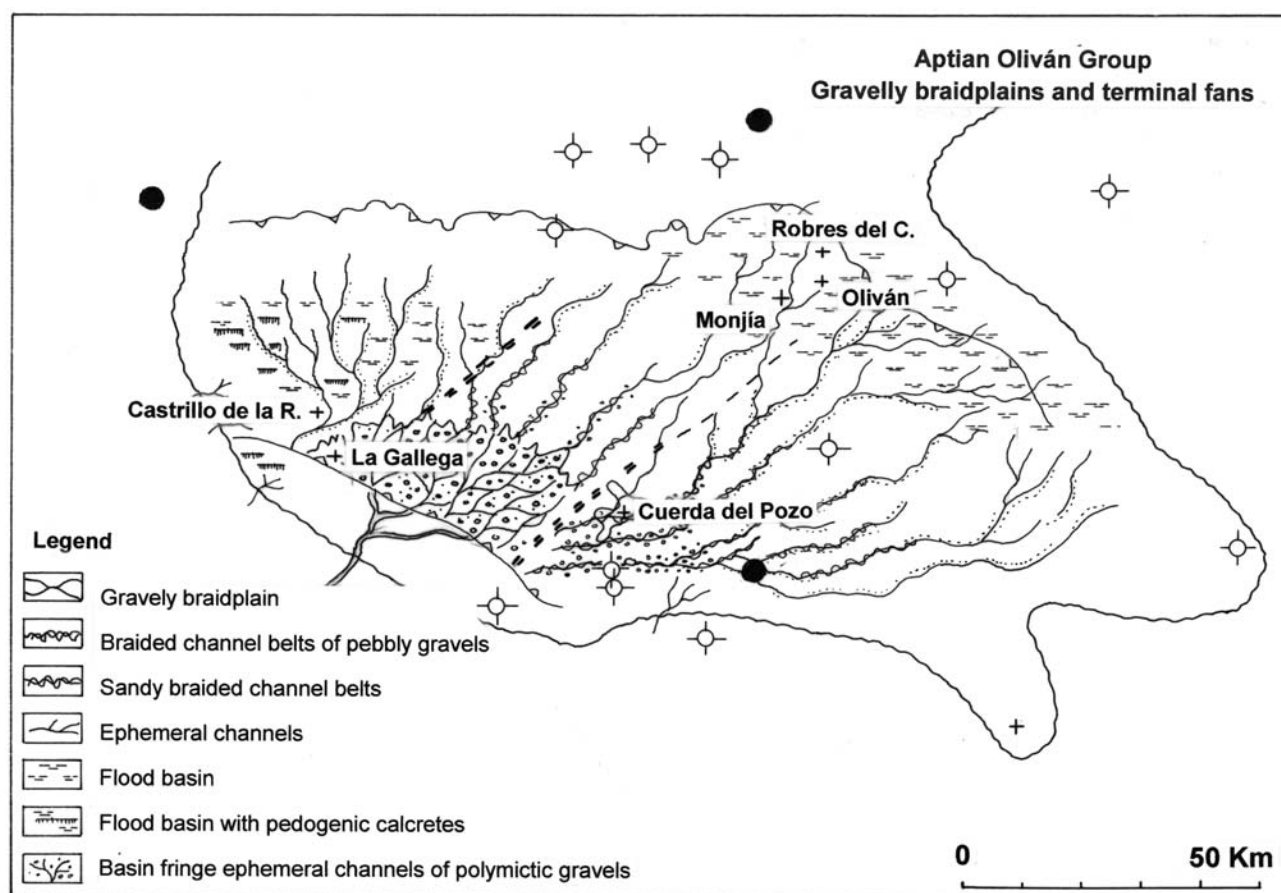


Figure 35.- The Aptian palaeogeography represented by the Oliván Group: a large and compartmentalized fluvial basin encompassing an extensive gravelly braidplain in the Western Cameros Central Sector, a large terminal fan in the Soria-South Cameros Sector and the middle-distal flood deposits of one/several terminal fans in NW/SW Cameros.

Camariñas Formation. In the terrigenous starved northern margin it could be correlative with the lacustrine coastal carbonates of the Cantaperdius Formation and in the basin depocentre the marine carbonates of the Artoles Formation of Canerot *et al.* (1982) and of Salas *et al.* (1995, 2001).

This basin stage is also well known in the Organya basin, it is represented in the basin depocentre by the marine carbonates of La Prada Formation of Peybernes and Bilote (1971a), Rosell and Llompart (1982), Berástegui *et al.* (1990); Bernaus *et al.* (2003); Conrad *et al.* (2004) and in the basin margin located in Montsec thrust sheet by the transitional to lacustrine carbonates with charophytes gastropods and foraminifers of Rosell and Llompart (1982) Schroeder *et al.* (1982), Peybernes and Combes (1994) and Robador and García Senz (2004). Towards the east, in the Figueras-Montgry Thrust Sheet by the Montgry Formation of Peybernes and Bilote (1971b) and Rosell and Llompart (1982).

The Aptian terrigenous progradation of the Oliván Group

The Oliván Group consists of five formations laterally related by facies changes and dominated by fluvial deposits La Gallega, Castrillo de la Reina, Cuerda del Pozo and Robres del Castillo (Fig. 35).

In Western Cameros Central Sector the Group is represented by La Gallega Formation, in NW/SW Cameros by the Castrillo de la Reina Formation and in the Soria-South Cameros Sector by the Cuerda del Pozo Formation (Fig. 35). They gradually change towards the basin depocentre to the Monjía and Robres del Castillo Formations (Fig. 35). Aeolian deposits are interbedded with the proximal alluvial facies of La Gallega and Cuerda del Pozo formations.

The Group represents a basin supplied by several fluvial systems, with a SW-NW, N, NE trend (Fig. 35). The proximal fluvial environments where the gravelly braidplain of La Gallega and the large braided channel belts of Cuerda del Pozo Formation (Fig. 35). The medial-distal fluvial deposits are represented in NW/SW Cameros by the Castrillo de la Reina Formation and in the basin depocentre by the Monjía and Robres del Castillo Formations (Fig. 35).

Time equivalent deposits in the Basque-Cantabrian basin probably are the Río Yera, Ereza, San Roque del Río Miera, Puerto de las Estacas and Río Trueba Formations of García Mondejar (1982) and of García Mondejar *et al.* (2004); in the Maestrazgo basin correlative deposits are the Morella, Cervera, Xert, Forcall, Villarroja de los Pinares of Canerot *et al.* (1982), Salas *et al.* (1995, 2001); in the South Iberian Trough the Contreras, Malacara El Bungal and El Buseo Members of the Caroch Formation of Vilas *et al.* (1982a).

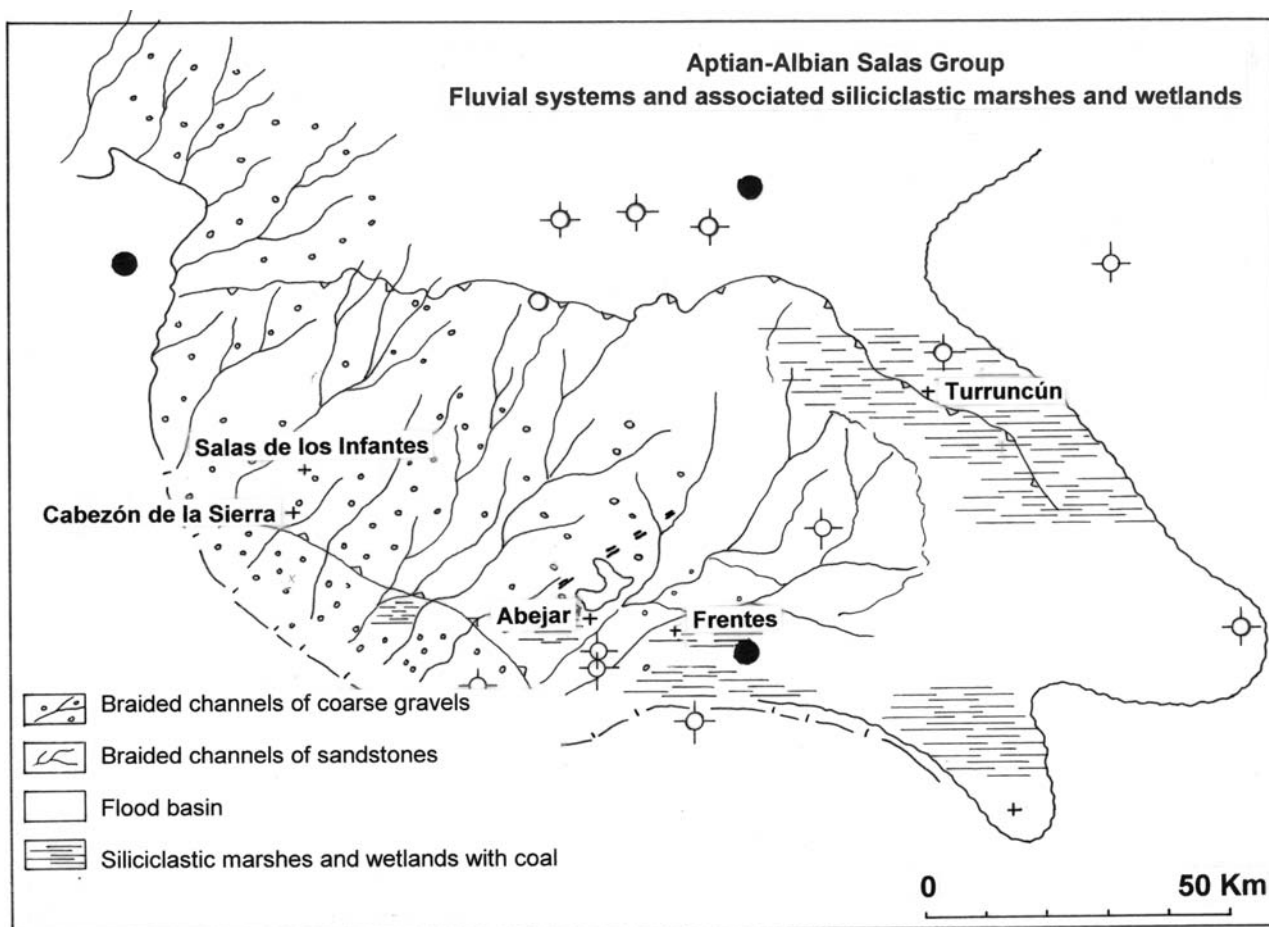


Figure 36- The Aptian-Albian palaeogeography represented by the Salas Group: extremely large fluvial systems and associated siliciclastic marshes and wetlands

During this basin stage, similar fluvial progradations (but of smaller dimensions) to the one represented in the Cameros basin by the Oliván Group took place in other Iberian basins. They could be represented by the fluvial deposits of the Río Yera Formation by García Mondejar (1982), in the Basque-Cantabrian basin by the Morella Formation in the Maestrazgo basin of Canerot (1973) and Salas *et al.*, (1995) and by El Bungal Member of the Caroch Formation in the South Iberian Trough of Vilas *et al.* (1982), Meléndez and López-Gómez (2003). Now also the volume of fluvial deposits in the basins of the Biscay Bay realm, in the Basque-Cantabrian and Cameros basins was larger than in the basins of the Tethys realm, in the Maestrazgo basin and in the South Iberian Through which again suggest different rates of tectonic uplift and of terrigenous supply from the Iberian Massif.

Overall, during this basin stage Cameros appears to have been a hydrologically closed basin but the presence of a marine intercalation in the basin depocentre (Mas *et al.*, 2002, 2004) and in SW Cameros (this work) point towards it was temporary open. Most likely it was connected with the shallow marine environments of the Montoria Formation of Ramírez del Pozo (1971) only 35 km north of the Cameros basin in the unbalanced tectonic section of the hanging wall of the Sierra de Cantabria Thrust.

The Aptian-Albian Salas Group terrigenous progradation

The Salas Group of Western Cameros is represented by the Cabezón de la Sierra and Abejar Formations and in Eastern Cameros the Group is cropping out in the hanging wall of the Turruncún Thrust where it is 150-200 m thick and consists of distal fluvial deposits, heterolithic facies and coal (Fig. 36). Fluvial and aeolian deposits are frequently interbedded.

The Salas Group is the deposit of a huge fluvial system, frequently reworked by aeolian processes. It implied an enormous progradation of terrigenous from the Iberian Massif.

Correlative deposits in the western margin of the Basque-Cantabrian basin probably are the Nogaró cyclothems of Ramírez del Pozo (1969, 1971); Las Rozas, Quintanilla de An, La Mesa and Olleros de Paredes Rubias conglomeratic units described by García Mondejar (1982), Martínez de Rituerto-Ibisate and García-Mondejar (2001a,b, 2003a,b). Probably it is also correlative with the fluvial deposits of the Vozmediano Formation of Jonker (1972) cropping out in the hanging wall of the south Cantabrian Mountains thrust (Fig.1). As described above, in the sub-surface of the Sierra de Cantabria Thrust correlative deposits are up to 2000 m and dominated by terrigenous facies (Lanaja *et al.*, 1987). Sedimentology and palaeocurrents by Ramírez del

Pozo (1971) and García Mondejar (1990) indicate a direction of sediment transport from the south towards the north. Most likely the proximal areas were the fluvial environments of the Salas Group.

Correlative deposits in the north and NW margin of Maestrazgo basin could be the Escucha Formation and the lower part of the Utrillas Formation of Aguilar *et al.* (1971), Querol *et al.* (1992). Following Rodríguez López *et al.* (2009) the lower-middle part of the Escucha Formation represents several genetic units, originated by a coal bearing system, whereas the upper part of the Escucha and the Utrillas Formations represent two genetic units originated by a desert system and controlled mostly by climate.

The upper part of the Salas Group has been correlated and genetically related by Rodríguez López *et al.* (2010) with the aeolian bearing facies genetic units described in the upper part of the Escucha Formation and lower part of the Utrillas Formation. The genetic relation however appears to be unlikely providing the overall regional gradient of Cameros basin towards the N, NW and NE. It is thought that the Upper Cretaceous palaeogeography represents a further but gradual step of the Upper Jurassic-Lower Cretaceous palaeogeography. Therefore the gradient towards the north is also supported by the NW polarity of the Upper Cretaceous carbonate platforms and the overall directions of the marine incursions from the NW, from the Biscay Bay towards the SE, towards the Tethys reported by Alonso *et al.* (1993).

Nevertheless, in the Cameros basin the climatic changes appear to have been less dramatic than the ones reported by Rodríguez López *et al.* (2009) in the Maestrazgo basin. In the Cameros basin large part of the basin evolution took place under rather arid climate from the Tithonian-Berriasian Señora de Brezales piedmont systems and extensive calcitization, to the evaporitic carbonate lakes of the Oncala Group or the ephemeral fluvial systems of the Oliván Group. The first aeolian sandstones have been described in the Peñacoba Formation (Arribas *et al.*, 2003), they also occur in the Oncala Group Jaramillo de la Fuente Formation and in the Urbión and Oliván Groups. In the Salas Group aeolian deposits occur in the lower and middle part of the Group and become more prominent in the upper part.

The type and distribution of facies associations, in the SW margin of the Asturias, Basque-Cantabrian and Cameros basin point towards the homogenization of the Biscay Bay realm margins, it is also possible the homogenization of the Biscay Bay and Tethys realms. These new fluvial progradations evidence a new and most important uplift phase in the Iberian Massif.

The Utrillas Formation and the Upper Cretaceous carbonate platforms

The Upper Cretaceous was a 30-35 m.y. long post-rift period of tectonic stability and thermal subsidence. This basin stage was characterised by the homogenisation of the Biscay Bay and Tethys realms and was marked with the progressive onlap of fluvial deposits of the Utrillas Formation on pre-rift mega-sequence and on the Variscan basement (Fig.1; Julivert

et al., 1972, Floquet *et al.*, 1982, Salomon, 1982a,b, Gil and García, 1996). The sub-tropical latitudinal position of Iberia and associated warm climate favoured the deposition of shallow marine carbonates.

In the Cameros basin, the Utrillas Formation represents the deposits of a wide coastal plain with small channels genetically related with overlying Santa María de Las Hoyas shallow marine limestones. This sedimentary environment represents a sharp change with respect to the underlying fluvial and aeolian environments of the Salas Group. The fluvial system evidences a decrease in the size of transported load from a system with a large volume of quartzitic gravels to a system with sands and with a large concentration of suspension load. Similar changes have been described by Ruiz and Segura (1993) in the South Iberian Through.

Synchronous vs. diachronous rifting and basin model: compartmentalized basin vs. multiple sub-basins

The characteristics of basins evolving under synchronous and diachronous rifting have been briefly presented in the introduction. Diachronous rifting implies a model where multiple sub-basins evolve independently (diachronously) and synchronous rifting a basin with multiple sectors evolving synchronously but under different rates of subsidence (Jackson and MacKenzie, 1983; Walsh and Watterson 1991, Morley 1989) and terrigenous supply.

The Alpine tectonics and stratigraphy of the syn-rift mega-sequence shows that the Cameros basin was compartmentalized into multiple sectors. The characteristics and basin wide distribution of six Groups Tera, Oncala, Urbión, Enciso, Oliván and Salas and the two independent formations Peñacoba and Cabretón indicates that rifting was a synchronous process.

The palaeogeographic evolution depicted in the previous section evidences a hydrologically closed or semi-enclosed basin compartmentalized into multiple sectors with differential rates of subsidence and terrigenous supply. The basin encompassed a terrigenous supplied margin in Western Cameros Central Sector with proximal fluvial environments, a basin depocentre with distal fluvial deposits and open lacustrine carbonates and evaporites; and several terrigenous starved margins around the basin depocentre and the terrigenous supplied margin (Figs. 30-36).

The six groups have a basin-wide distribution. They are represented in every basin sector: they are in the basin depocentre, terrigenous supplied and terrigenous starved margins.

The stratigraphy of the Groups shows 'lithologic affinity' with lateral facies changes between the different formations. In general, the groups encompass in Western Cameros thin formations consisting of proximal fluvial deposits which progressively change to the basin depocentre to thick formations made up of distal fluvial deposits or open lacustrine facies thin-bedded limestones, paper shales, marls and evaporites. These in turn change towards the margins to much thinner formations dominated by thick-bedded limestones and marls or by distal fluvial deposits with

palaeosols. The stratigraphy evidences a systematic distribution of sedimentary sub-environments during basin evolution (Figs. 28 to 36).

The basin-wide distribution of the Groups and changes in thickness and lithofacies supports a model where a basin is compartmentalised into multiple sectors evolving synchronously under different rates of subsidence and terrigenous supply. Furthermore, the relatively good correlations of the main tectono-sedimentary events, rifting and uplift phases in the Biscay Bay and Tethys realms point towards that at the scale of a small extensional province such as NE Iberia during the Upper Jurassic-Lower Cretaceous, rifting was also a synchronous process.

Morphology of the basin margins

The differences between basins with morphological relief and rift shoulders and basins with low gradient basin margins have been also briefly described in the introduction. Basins with morphological relief and rift shoulders are characterised with the basin depocentre attached to the basin margin, and with alluvial fan, fan deltas and deep lakes as distinctive sedimentary environments; subsidence in the basin is directly related with the uplift of the rift shoulders (Morley, 1989; Friedman and Burbank, 1995).

At the other end of the spectrum are basins with low-gradient basin margins which are further characterised because the basin depocentre is detached from the basin margins (Morley, 1989; Friedman and Burbank, 1995) and the characteristic sedimentary environment are extra-basinal fluvial systems, basin fringe rivers and shallow carbonate lakes.

In the case of the Cameros basin and also of many of the remaining Upper Jurassic-Lower Cretaceous Iberian basins, the onlap the syn-rift mega-sequence on the terrigenous supplied or terrigenous starved margins, the preservation of the pre-rift mega-sequence at the basin margins and the characteristic sedimentary environments: extra-basinal fluvial systems and shallow carbonate lakes or marine platforms point towards basins with low gradient basin margins.

Conclusions

The formal stratigraphy of the Western Cameros Upper Jurassic Lower Cretaceous has been reviewed. In this sector of the basin the stratigraphy is condensed but equally developed as in the basin depocentre. The Tera Group consists of two formations, Señora de Brezales and Magaña. The Oncala Group encompasses three formations, Jaramillo de la Fuente, Río del Salcedal and Rupelo. Peñacoba is an independent formation mostly of biogenic lacustrine carbonates unconformable overlying the marine Jurassic, Tera and Oncala groups. The Urbión Group is represented by the Laguna Negra Formation. The Enciso Group consists of three formations, Río Ciruelos of fluvial origin, Hortigüela of fresh water lacustrine carbonates and Golmayo of fluvial dominated coastal plain with diluted lakes. The Oliván Group is represented by three formations of fluvial deposits, Castrillo de la Reina, La Gallega and Cuerda del Pozo and the Salas Group with

the Cabezón de la Sierra and Abejar Formations. In the terrigenous supplied margin, the syn-rift mega-sequence encompasses up to eight distinctive units of quartzitic conglomerates, (Laguna Negra, Río Ciruelos, La Gallega, Cabezón de la Sierra and Península de Herreros, Alto de La Negrada and El Henar).

The basin-wide distribution of the Groups and their differential development across the basin indicates that rifting was a synchronous process and support a model of a basin compartmentalized into multiple sectors with different rates of subsidence and terrigenous supply.

The onlap on the basin margins, the sedimentary environments, large, extra-basinal fluvial systems and shallow carbonate lakes, the condensed character of the syn-rift mega-sequence, the preservation of the pre-rift mega-sequence at the basin margins point towards a basin with low gradient basin margins.

Acknowledgements

I would like to thank Ida Lykke Fabricius from Civil Engineering- Centre for Energy Resources Engineering - DTU for to her welcome to the research group and for supervision. Thanks also to Arne Villumsen from the Civil Engineering - Arctic Center - DTU for helping with my return to the University and to Alfred Riis from the Center for Beskæftigelse, Sprog og Integration (CBSI) who kindly worked out the necessary administrative arrangements.

The paper was initially part of a PhD project in the Departamento de Estratigrafía de la Universidad Complutense de Madrid and later on of an EU project in the Delft University of Technology (TU Delft) from where I kindly thank Rick Donselaar (TU Delft). I'm grateful to Professor David Batten (Manchester University) for studding the pollen and spores, to Julio Rodríguez Lázaro (Universidad del País Vasco) which studied the ostracods.

I cannot forget, the many friends that were around when I started working and helped in a large variety of tasks, from field work to review. Special thanks to Gemma Martinez and Francisco Salinas from the Department of Paleontology, FCCG-UCM, Javier Martín-Chivelet, Rocío Jimenez, Lourdes, María Antonia Fregenal from the Department of Stratigraphy FCCG-UCM; Daniel Rey and Marta Pérez-Arlucéa from Vigo University, Tomas Vázquez from the Cadiz University, Luis Barranco (Protección Civil), Ana Alonso, Carlos Rossi and Cecilia Pérez-Soba from the Department of Petrology FCCG-UCM; Inmaculada Gil Peña from the Spanish Geological Survey (IGME) Yolanda Martinez Jalvo, María Jose Amores and Pablo Pelaez Campomanes from the Natural Sciences Museum, CSIC, Madrid and Daniel Mikes from Stellenbosch University of South Africa. The comments and suggestions by the referees of the journal, Jose Miguel Molina and Charles Martín Closas contributed to improve the original manuscript. Final thanks to Juan Antonio Morales editor of la Revista de la Sociedad Geológica de España and to Xiomara Cantera of Proedex s.l. for helping with the figures.

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Manuscrito recibido el 2 de marzo de 2011

Aceptado el manuscrito revisado el 21 de junio de 2011